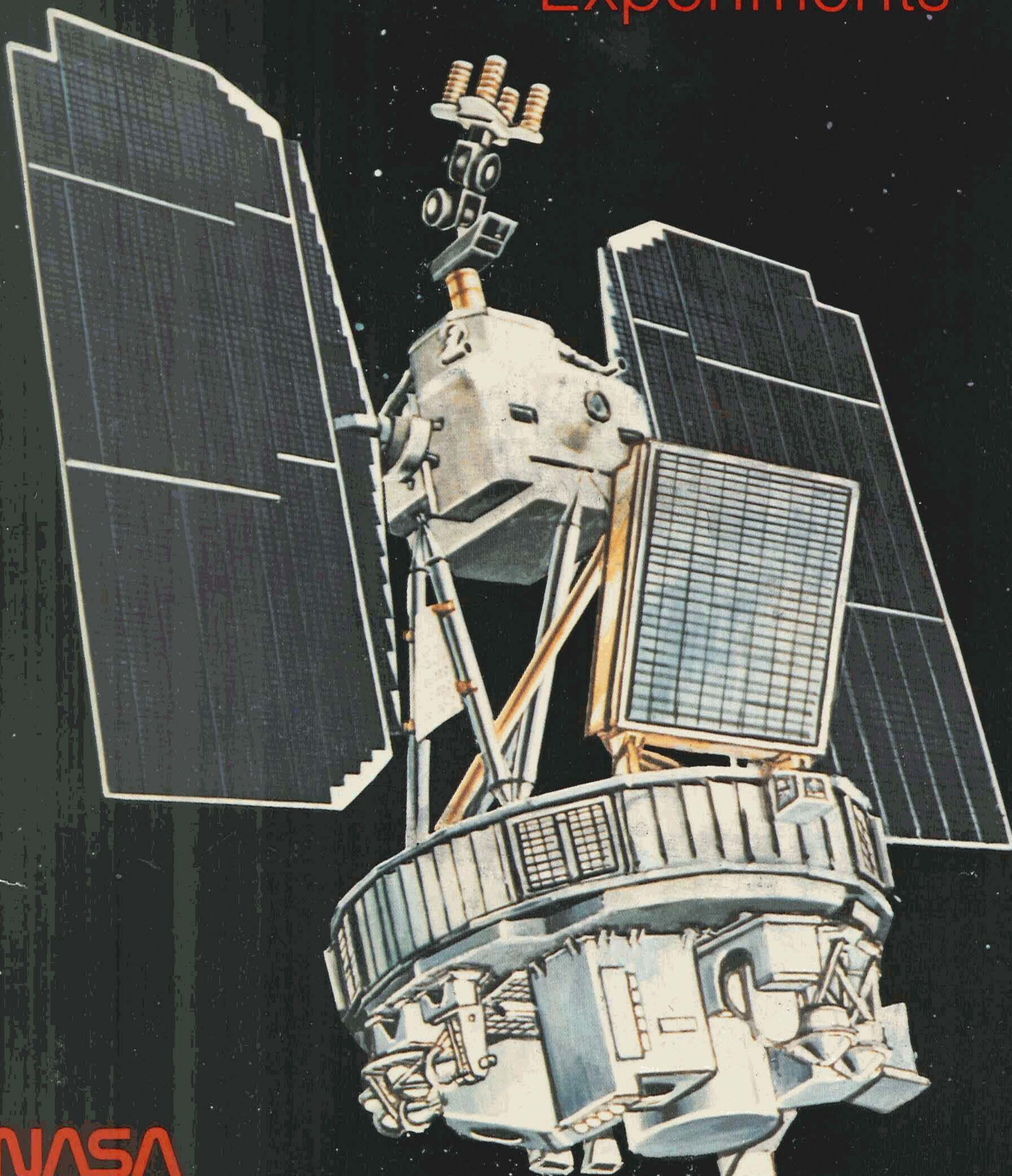
NASA SP-457

Nimbus 6 Random Access Measurement System Applications Experiments



NASA

NASA SP-457

Nimbus 6 Random Access Measurement System Applications Experiments

Editors
Charles Cote, Ralph Taylor, and Eugene Gilbert
Goddard Space Flight Center

NASA

Scientific and Technical Information Branch 1982
National Aeronautics and Space Administration
Washington, DC

Library of Congress Cataloging in Publication Data

Main entry under title:

Nimbus 6 random access measurement system applications experiments

(NASA SP ; 457)
October 1982.
Includes bibliographical references and index.
1. Random Access Measurement System. 2. Nimbus (Meteorological satellite). 3. Atmospheric research. 4. Oceanographic research. 5. Polar regions—Research. I. Cote, Charles (Charles E.) II. Taylor, Ralph E., 1923– . III. Gilbert, Gene. IV. Goddard Space Flight Center. V. Title: Nimbus 6 random access measurement system applications experiments. VI. Series.
QC808.5.N55 1982 551.5'072 82–14553

Foreword

The success of scientific and engineering experiments using instrumented drifting or moving platforms transmitting data to the random access measurement system (RAMS) on the Nimbus 6 polar orbiting satellite was the result of the work of a number of imaginative and resourceful principal investigators and the response and cooperation of their respective organizations in Government, universities, and industry around the world.

The program included 49 experiments from countries including Norway, France, the United Kingdom, Australia, Canada, Denmark, and the United States. The experiments varied from Earth circling, meteorological balloons, and oceanborne drifting buoys to environmental measurements on land. Each of the experiments and the principal investigators participating in the program are listed in the appendix to this publication.

During the course of the program, many technological and natural difficulties had to be overcome. The participating investigators and scientists met each challenge as it occurred. These efforts expanded our scientific knowledge and understanding and paved the way for future experiments of this nature. The dedication of all those involved in the program is acknowledged.

The Nimbus 6 RAMS program signaled the commencement of experiments that are continuing on the current series of environmental satellites. The Nimbus 6 RAMS experience led to the success of the ARGOS mission under the global atmospheric research program.

Charles E. Cote
Instrument Systems Division
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland

John Masterson
Consultant
National Center for Atmospheric Research
Boulder, Colorado

Table of Contents

Introduction

In the early 1960's, the Committee on Atmospheric Sciences of the National Academy of Sciences established a Panel on International Meteorological Cooperation to study the desirability and feasibility of a global observation experiment to measure the state and motion of the entire lower atmosphere. The objectives of the study were to evaluate the scientific needs for atmospheric observations on a global scale and to determine the technical feasibility of various observational systems.

The system appearing to offer the greatest promise in meeting the needs of the user community was a polar-orbiting satellite system that would transmit data gathered by constant-level balloons and fixed or drifting buoys while making radiometric measurements in the infrared and possibly the microwave regions of the electromagnetic spectrum.

To implement this system concept, experimental techniques were designed, developed, and flown over the years to locate and collect data from balloon and buoy platforms. One of the early experiments, the global horizontal observation sounding technique program, and very-low-frequency transmissions from Sun-angle sensors on balloons demonstrated the feasibility of using constant-level balloons circumnavigating the globe for long periods. Locations were determined by ground stations around the world. A satellite experiment called the interrogation, recording, and location system (IRLS) was launched on the Nimbus 4 meteorological satellite in April 1970. The IRLS successfully used the ranging technique to locate 30 balloons in the upper troposphere and lower stratosphere of the equatorial region. This experiment measured the trajectory of balloons and traced the winds of the quasi-biennial cycle. The Nimbus 4 IRLS also was used by the U.S. Navy Oceanographic Office to track a 12.5-m drifting spar buoy off the east coast of the United States. Meteorologic and oceanographic variables measured by the buoy included air temperature and water temperature.

The next generation of satellite location and data collection systems was tested with the EOLE satellite developed by the French space agency, Centre National d'Études Spatiales (CNES). In this experiment, 480 constant-level balloons were launched in the Southern Hemisphere mid latitudes. This experiment demonstrated the feasibility of locating large numbers of platforms from satellites and it provided the first significant lagrangian surface current data. The range-rate technique made it possible to locate the moving balloon platforms within 2 to 5 km.

Ten drifting discus buoys equipped with drogues and ocean temperature sensors were also tracked in the Northeast Pacific by the EOLE satellite. In addition, the EOLE was used to track five Navy-designed spar buoys in the southwestern North Atlantic Ocean. Both the Nimbus 4 IRLS and the EOLE system required that the satellite interrogate the balloon to receive data. The expense and complexity of satellite systems for interrogating platforms necessitated a simpler system. With the development of magnetic cutdown, which prevented balloons from drifting far into the Northern Hemisphere, a hemispheric balloon could function without platform interrogation; i.e., without a receiver for command cutdown. This new concept led to the development of the random access measurement system (RAMS) technique in which the platforms randomly transmit signals to the polar-orbiting satellite, thus eliminating satellite interrogation.

On June 12, 1975, the NASA Nimbus 6 meteorological satellite was launched with a RAMS on board. The Nimbus 6 RAMS not only served as the vehicle for the tropical wind, energy conversion, and reference level experiment (TWERLE), which used constant level balloons, but it also provided opportunities for a number of other applications investigations.

To evaluate the total capabilities of the RAMS concept, investigators from around the world were invited to conduct experiments from a variety of platforms. Among those responding to the NASA invitation to participate in using RAMS were oceanographers and polar investigators who wanted to track and retrieve data from ocean and ice buoys as well as from platforms on tabular icebergs. Several commercial oil drillers in the Arctic area deployed buoys and used the Nimbus 6 RAMS to measure currents bearing icebergs. Others engaged in land, sea, and air explorations have plotted their positions and locations with the Nimbus 6 RAMS. The first balloonists to cross the Atlantic used the Nimbus 6 RAMS for navigation and in-flight planning. Scientists also used the Nimbus 6 RAMS to track and locate various types of marine life.

Typical applications experiments performed during the 1975-79 period with the Nimbus 6 RAMS are highlighted in this book. The various principal investigators conducting RAMS experiments are listed by experiment/user number in the appendix to this book. These experiments and the results obtained with the Nimbus 6 RAMS characterize the contribution of the joint Government, university, industry, and foreign-nation teams that worked together to use the technology for new applications and to advance the capability in global observations. This work has paved the way for expanding satellite location and data collection technology to meet future applications and global observations requirements.

Principal investigators interested in future data collection experiments using the ARGOS system should contact

J. L. Bessis
User Relations Manager
Service ARGOS—Centre national d'études spatiales
18 Avenue Edourad Belin
31055 Toulouse Cedex
France
Telephone: (61) 53 11 12
Telex: 531 081 F

Nimbus 6: An Overview

The Nimbus satellite program was initiated by NASA in the early 1960's to develop an observatory system capable of meeting the research and development needs of the Nation's atmospheric and earth scientists and to provide global surveillance of atmospheric structure for low Earth-orbital altitudes for the world's weather services.

The first vehicle was launched in 1964, and, in the intervening years the project has matured to become the Nation's principal satellite program for remote-sensing research. Each observatory has grown significantly in sophistication, complexity, weight, capability, and performance.

The sixth NASA Nimbus satellite, carrying highly advanced meteorological, oceanographic, and Earth-surface sensing experimental payloads, was successfully launched from the Vandenburg Air Force Base Western Test Range on June 12, 1975.

Nimbus 6 was a butterfly-shaped satellite 10 ft tall and 5 ft wide, with a circular structure at its base that housed the major service subsystems and payload experiments. (See fig. 1.) A three-axis attitude control subsystem mounted above the sensory ring keeps the sensors pointed toward Earth with an accuracy of better than 1° about all axes. Two solar paddles track the Sun during daylight

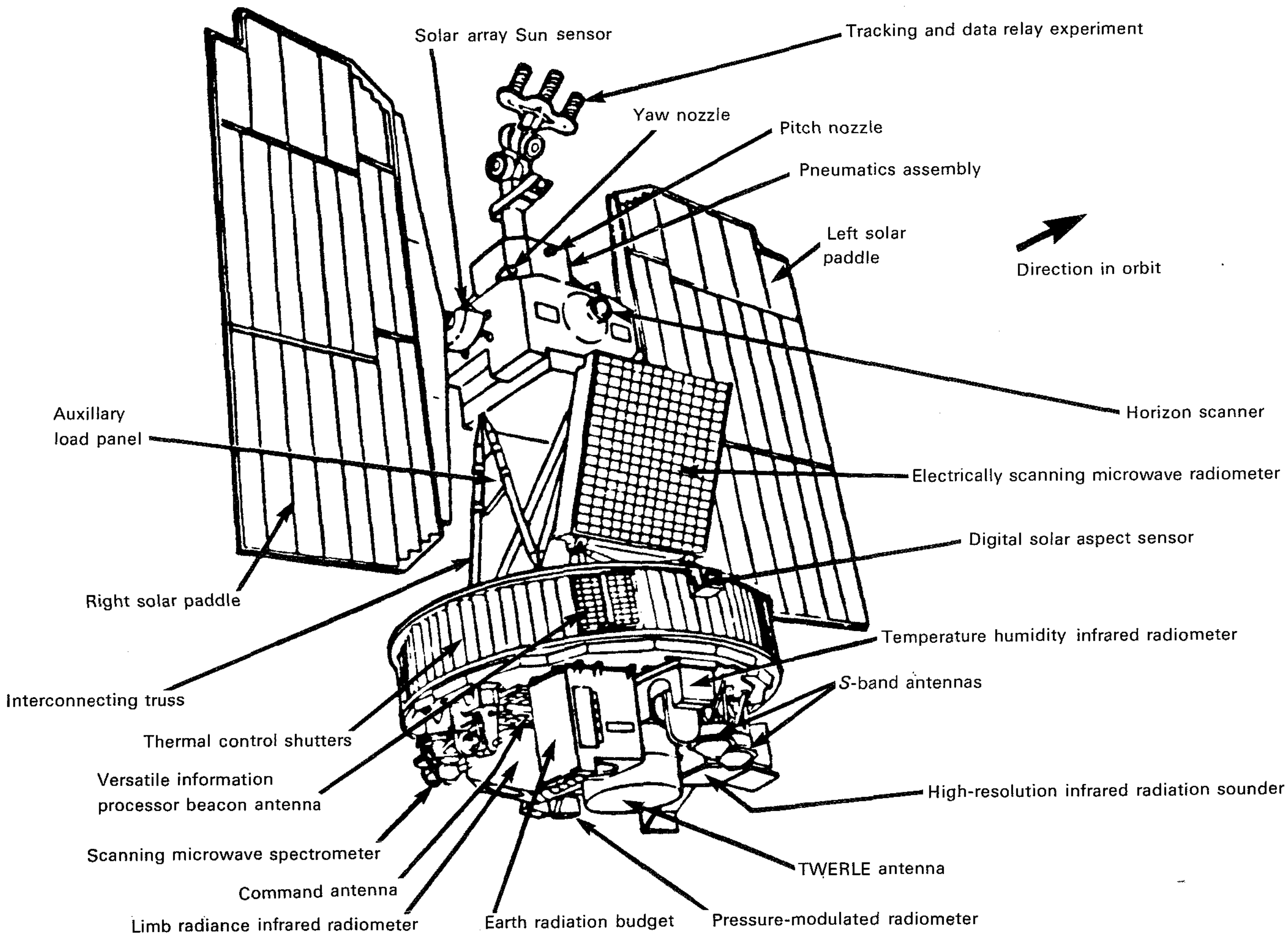


Figure 1.—Nimbus 6 configuration.

operation and convert its energy into power for spacecraft subsystems. This satellite was placed in a 1100-km Sun-synchronous polar orbit (fig. 2) having local noon (ascending) and midnight (descending) Equator crossings and an 81° retrograde inclination. Successive orbits cross the Equator with 26.8° of longitudinal separation; the orbital period is about 107.25 min, which results in approximately 13.5 orbits per day. A given point on Earth's surface is viewed twice in every 24-hr period, once in sunlight and once in darkness.

Mission Objectives

The mission objectives of Nimbus 6 are summarized as follows:

(1) Achieve a major milestone in the Global Atmospheric Research Program (GARP) by refining and further demonstrating techniques to measure global atmospheric mass and wind fields and by making observations for meteorological analyses for use in numerical models of atmospheric circulation

(2) Develop and demonstrate techniques for environmental monitoring from space by monitoring temperature and distribution of gases in the stratosphere, the planetary radiative energy budget, ice cover, sea state, and soil moisture

(3) Extend vertical sounding capability to the upper stratosphere and develop new sounding techniques

(4) Measure large-scale atmospheric motions and the conversion of potential energy to kinetic energy, and provide a 150-mb reference level in the Southern Hemisphere

(5) Measure sea ice, snow cover on ice, surface roughness, moisture, and liquid water content of clouds by using microwave imaging

(6) Develop new technology, data link and ephemeris, necessary for Earth observations

(7) Measure the synoptic and planetary Earth radiation budget.

(8) Evaluate the use of satellites for location and retrieval of data and mobile platforms in the atmosphere, oceans, and lithosphere.

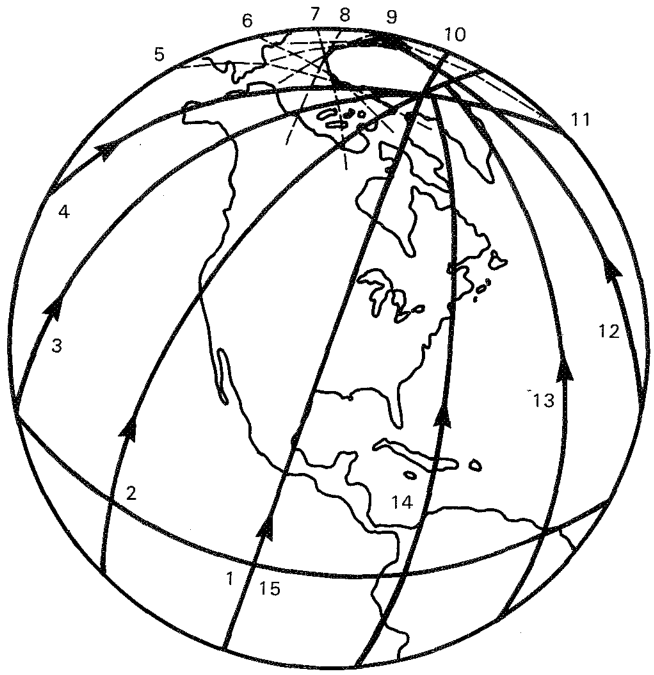


Figure 2.—Nimbus 6 daily repeating orbital pattern (14 orbits per day).

Payload Experiments

The Nimbus 6 observatory contains nine experiment payloads, a digital solar aspect sensor, and the integrated subsystem required to support the payloads in orbit, including—

(1) Earth radiation budget experiment
(2) Electrically scanning microwave radiometer
(3) High-resolution infrared radiation sounder
(4) Limb radiance infrared radiometer
(5) Pressure-modulated radiometer
(6) RAMS, which is the observatory portion of the TWERLE
(7) Scanning microwave spectrometer
(8) Tracking and data relay experiment
(9) Temperature/humidity infrared radiometer

Random Access Measurement System

RAMS on Nimbus 6 was the spaceborne portion of the TWERLE. Soon after its successful operation it became one of the most widely used systems in the spacecraft. Because of excess capability in RAMS on the Nimbus 6 satellite, guest investigators were invited by NASA to participate in experiments in which the special positioning and data collection system could be of particular advantage.

The design capability of RAMS to receive 1-s transmissions from numerous remote sensors or transmitter packages located on balloons or other platforms on or near Earth brought a new applications potential—the ability to locate and retrieve data from a number of fixed and mobile platforms in the ocean, on ice, over land, and in the atmosphere.

Investigators from around the world in Government, universities, industry, and the private sector were invited to participate in a variety of applications and discipline-oriented experiments that could use the technology and capabilities of the Nimbus 6 RAMS payload.

Operation

RAMS had five basic functions relative to each signal received from a platform:

(1) Detect signal presence and pass it to one of eight parallel processing paths in the system

(2) Detect the platform identification code and the sensor data

(3) Determine the received signal carrier frequency

(4) Determine the time of arrival of the signal at the spacecraft

(5) Format the resulting data and transfer it to the spacecraft information processor for subsequent storage or transmission to Earth

Each platform on or near Earth transmitted a signal at a carrier frequency of 401.2 MHz at the spacecraft for a period of 1 s each minute. This signal consisted of a short burst of continuous wave carrier followed by 100-bps carrier modulation containing an alternating 1/0 pattern; a unique synchronization word; the balloon, buoy, or platform identification code; and data from the sensors.

In the spacecraft, the RAMS consisted of a receiver, signal processor, and an antenna. The receiver was a standard module weighing about 13 lb. The signal processor was a standard module, with a 2.3-in. penthouse, weighing about 23 lb. Power consumption was 14 W in the receiver and 25 W in the signal processor. The antenna was a cavity-backed spiral with right-hand circular polarization.

RAMS could receive up to eight simultaneous transmissions although the Nimbus 6 satellite could view over 100 different platforms at one time.

As the Nimbus 6 spacecraft passed over the various platforms on or near Earth, RAMS detected and acquired the incoming platform transmissions, distinguished the platforms by their identification codes, and determined the location of the transmitter platform from the doppler shift in which the variation in the received frequency of the ground transmitter is analyzed to determine platform position.

Applications Experiments

During the 4-year operational lifetime of the Nimbus 6 spacecraft, the Nimbus 6 RAMS worked with more than 75 different investigators performing experiments around the world. The experiments included—

(1) Atmospheric and stratospheric experiments
(2) Oceanographic experiments
(3) Arctic and ice experiments
(4) Marine life tracking experiments
(5) Navigation and position location experiments
(6) Data buoy development experiments

The Nimbus 6 RAMS mission afforded the opportunity to assess and evaluate the potential for using polar-orbiting satellites for location and retrieval of data from a variety of mobile platforms. Applications experiments used in this evaluation are summarized in subsequent sections. These experiments exemplify the potential for merging satellite technology and space capabilities with innovative research and new applications requirements.

Atmospheric and Stratospheric Experiments

During the 4-year operational lifetime of the Nimbus 6 satellite, several investigations and experiments falling within the atmospheric and stratospheric meteorological discipline area were undertaken with RAMS. The most prominent of these experiments was TWERLE, for which RAMS was originally deployed. TWERLE was a continuation of free-balloon atmospheric research projects. Two foreign-nation experiments were also conducted: the Australian drifting buoy experiment and the Northeast Greenland weather data experiment by Denmark. The National Center for Atmospheric Research (NCAR) mountain wind project was designed to obtain wind data from the slopes of the Colorado Rockies with remote sensors that provided data to the Nimbus 6 RAMS.

Tropical Wind, Energy Conversion, and Reference Level

Dr. Paul Julian, *National Center for Atmospheric Research, Experiment/User No. 2*

The primary experiment flown on the Nimbus 6 satellite that used the RAMS payload capability was the tropical wind, energy conversion, and reference level experiment (TWERLE). TWERLE was a GARP-related experiment and a joint project of the NASA Goddard Space Flight Center (GSFC), the University of Wisconsin, and NCAR.

The RAMS was designed to locate and collect dat: from a large number of drifting platforms. In the case o TWERLE, these platforms were instrumented, super pressurized balloon platforms designed to float on ε constant density surface (0.250 kg/m^3). The TWERLI platforms contained sensors for measuring atmospheri(pressure, temperature, and altitude. (See fig. 3.)

The scientific objectives of the experiment were a: follows:

(1) To obtain adequate density of wind and temperature measurements in the tropical upper troposphere tc study the interactions of tropical circulation systems with those of middle latitudes

(2) To obtain data on the pressure gradients along balloon trajectories that can be related to the rate at which potential energy is converted to kinetic energy in the uppe1 atmosphere

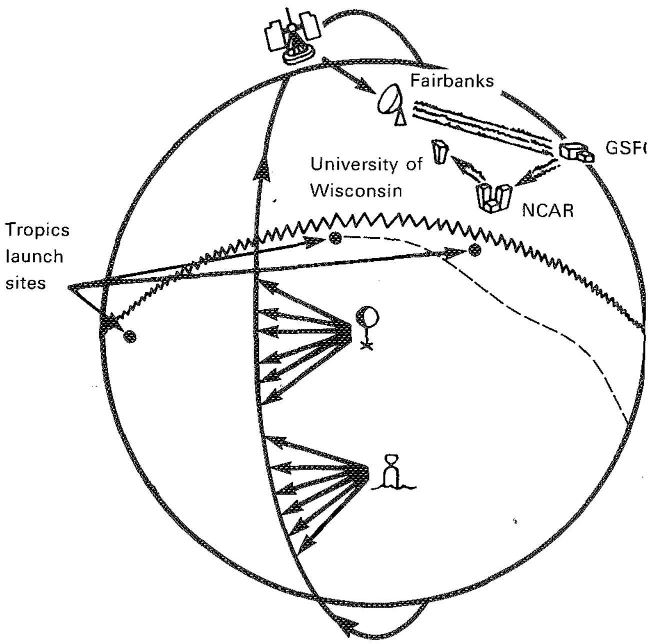


Figure 3.—TWERLE configuration. In TWERLE, 400 super pressure balloons were launched in the tropics and transmitte(data to the polar-orbiting Nimbus 6 meteorological satellite which processed signals and relayed them to ground stations. Th RAMS aboard Nimbus 6 also relayed data from drifting buoy and other GARP oceanographic experiments.

(3) To study the need for the characteristics of an in situ measurement of pressure and temperature at a known geometric altitude (the principal use of reference information would be to provide a fiducial point for remote atmos-

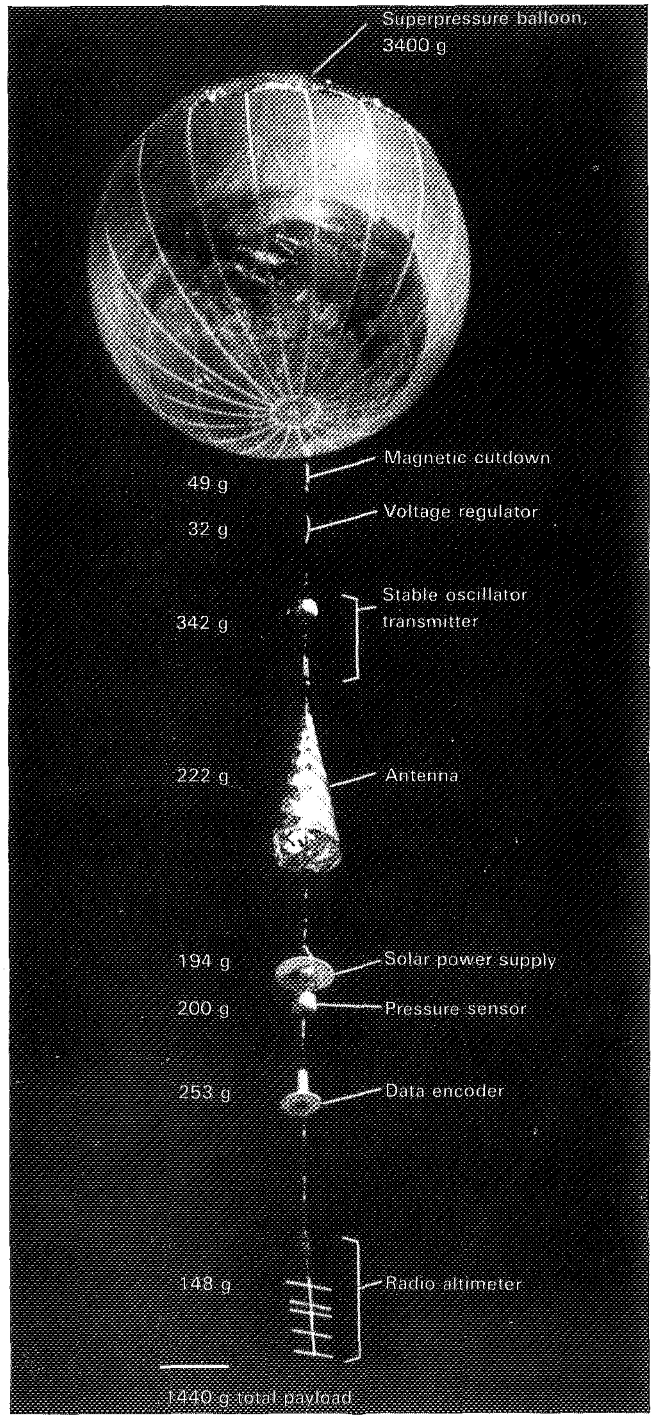


Figure 4.—TWERLE balloon.

pheric temperature sounders such that sounder data can be more accurately assimilated by large global atmospheric circulation models)

(4) To investigate various modes of gravity waves in the upper tropical troposphere and lower mid-latitude stratosphere.

The Nimbus 6 location and data collection system resulted in a successful effort to test a simple, reliable system that used low-cost expendable balloons. The concept of a random doppler system gave simplicity at low cost with no sacrifice in position accuracy. An instrumented balloon platform not only provides reference information for a global-observing system but also has proven that probing of various kinds of gravity wave activity at balloon altitude is feasible.

The TWERLE platform consisted of the nonextensible 3.5-m-diameter balloon envelope, electronics, solar-cell array, and antenna to transmit 400-MHz signals to the Nimbus 6 spacecraft once each minute. (See fig. 4.) In addition, each platform carried sensors to detect ambient temperature, pressure, and geometric altitude above the sea surface. Also, a geomagnetic field sensing device was incorporated into the balloon train to cut the platform down should it move north of 20° N geomagnetic latitude. On the daylight portion of each orbit, the spaceborne equipment detected, demodulated, and stored the doppler signals and sensor telemetry for platforms within range of the satellite. Processing of the doppler signal on the ground provided the position and velocity of the platform.

The flight level of the balloons was at a nominal atmospheric density level, 0.250 kg/m^3. Thus, in the tropics the flight level was in the upper troposphere at 140- to 150-mb pressure, whereas at mid and high latitudes, in the lower stratosphere, the pressure range was 150 to 170 mb.

A total of 393 TWERLE balloons were successfully launched: 47 from Accra, Ghana; 109 from Ascension Island; 102 from American Samoa; and 135 from Christchurch, New Zealand.

As the balloons were carried aloft by winds, they transmitted to the Nimbus 6 satellite pressure, temperature, and altitude data for 1 s out of every minute at their float level (150 mb).

Figure 5 illustrates the coverage achieved by the platforms. The Mercator projection shows the number of reports totaled over a 30-day period (mid-August to mid-September 1975) in 15° longitude/latitude segments. During this period an average of 95 balloon platforms launched from Ascension Island and Samoa were tested. The high concentration of platforms in the immediate vicinity of and immediately downstream of these launch sites is expected. In addition, a band of relative high report density can be seen at the latitude (~20° S) of the subtropical jet stream. Moreover, a large number of platforms are grouped in the tropical Atlantic region, and there is a virtual absence of reports in the vicinity of the monsoonal easterly flow over northern Africa, the Indian Ocean, and Indonesia.

An interesting observation from the Christchurch, New Zealand, experiment was that only about 25 percent of the balloons launched entered the Northern Hemisphere. Of 135 balloons, 33 crossed the Equator into the Northern Hemisphere at various points in their trajectories and 6 others came within a degree or two of doing so.

Two major conclusions resulted. First, the trajectories entering the Northern Hemisphere out of the mid-southern latitudes were primarily an austral summer phenomenon. Second, the trajectories were related to the mid-oceanic troughs located at about 200° E and 320° E longitude, corresponding to the mean positions of these troughs. Clearly, in the mechanism of interhemispheric mass transfer and mid-latitude interaction with the trophics, the mid-ocean troughs play a key role.

The basic output used in the reference level portion of the experiment is the Southern Hemisphere polar stereographic 150-mb map (fig. 6). Both TWERLE data (marked with a T) and conventional upper atmospheric

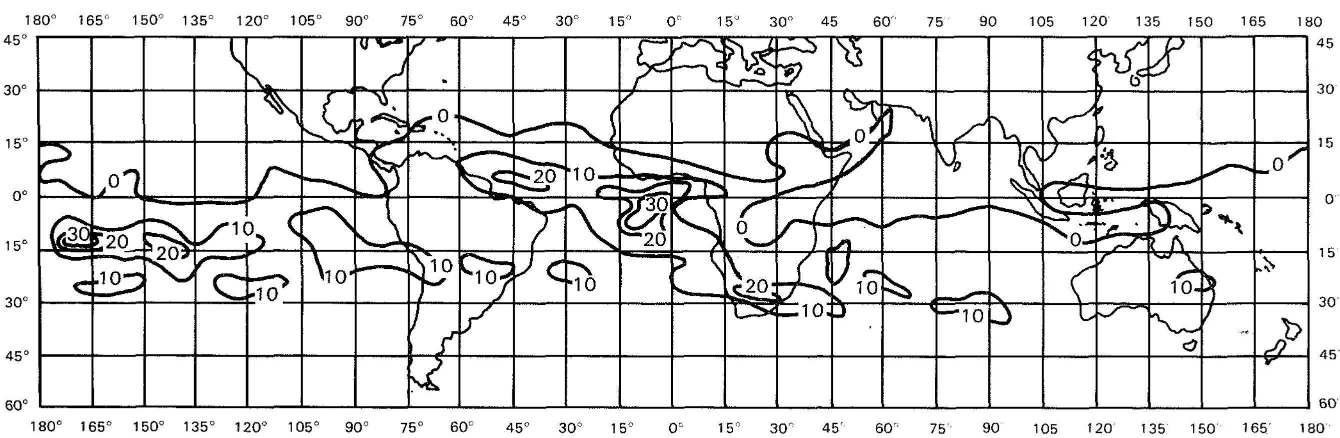


Figure 5.—A Mercator projection showing number of reports totaled over a 30-day period in each 15° longitude/latitude segment.

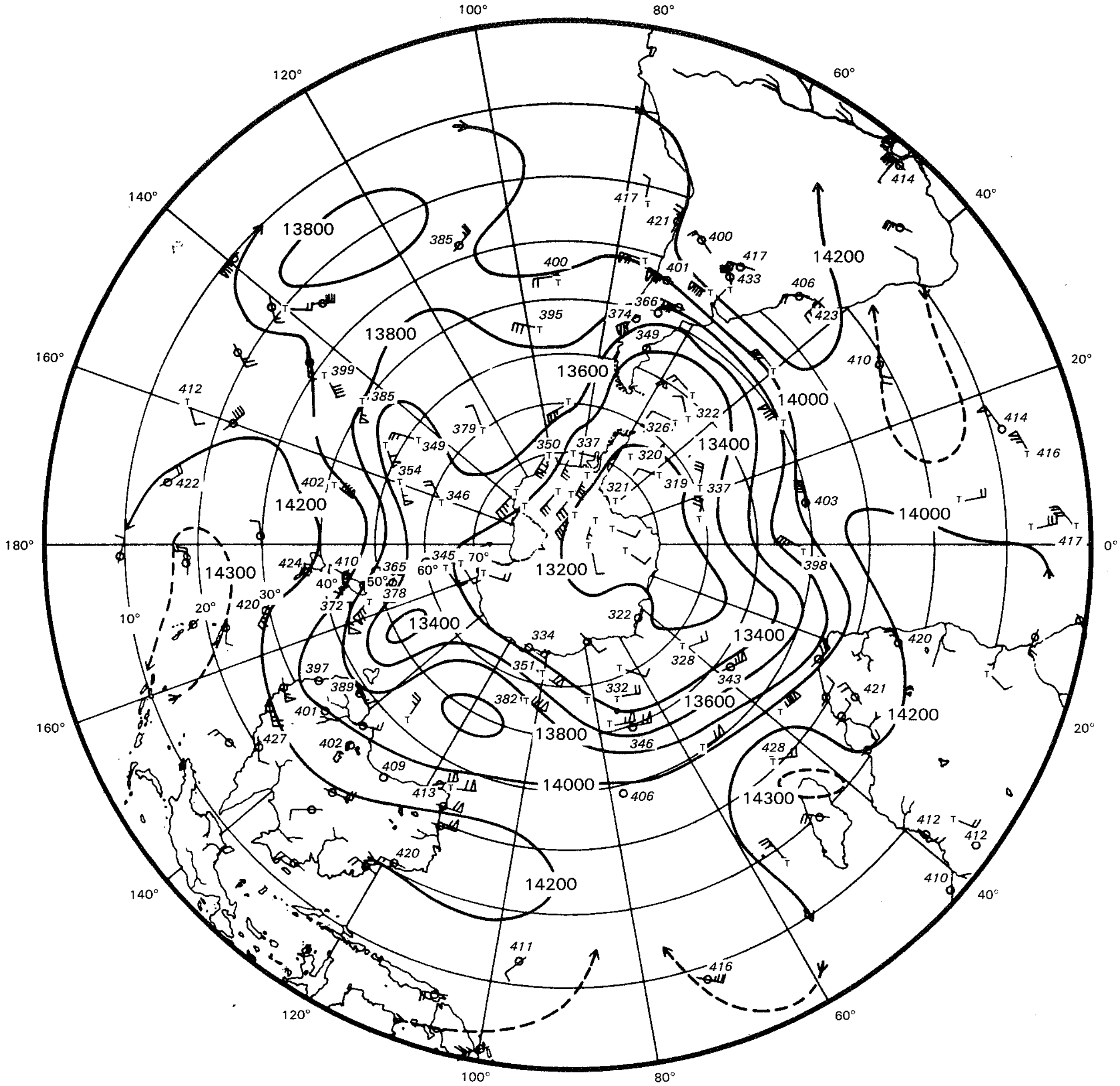


Figure 6.—A Southern Hemisphere polar stereographic 150-mb map constructed by TWERLE data and conventional upper atmospheric soundings.

soundings (marked with circles) were used to construct this map. The numbered solid lines (e.g., 14200) indicate the dynamic height of the 150-mb pressure level in meters, and the wind arrows show the observed wind information in standard meteorological notation. (True wind direction is shown by arrows flying *with* the wind. Wind speed is indicated by flags and feathers: each flag represents 50 knots, each full feather 10 knots, and each half feather 5 knots.)

Analysis of the pressure or altitude data shows various gravity wave modes that affect balloon motion. In figure 7, neutral balloon oscillation (NBO) with a period of about 4 min is shown together with an indication of a vertical

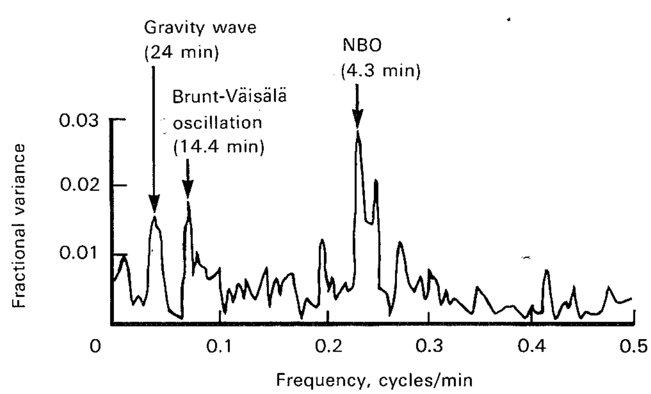


Figure 7.—Spectrum of vertical balloon movement.

buoyant oscillation characteristic of the surrounding air (period of about 14 min) and also large-scale gravity waves (periods of about 24 min).

The TWERLE experiment successfully demonstrated the extraordinary flexibility and utility of an instrumented superpressure balloon system using a satellite system such as RAMS for data collection and position-location determination.

Australian Drifting Buoy

Dr. H. N. Brann and Dr. D. E. Handcock, *Department of Science, Experiment/User No. 28*

The Australian drifting buoy experiment was designed to investigate the effectiveness of free floating buoys to support atmospheric modeling over the South Indian and Southern Pacific Oceans. The experiment was conducted by the Australian Bureau of Meteorology and funded by the Australian Government. The purposes of the experiment were as follows:

(1) To measure air pressure and sea surface temperature from free drifting buoys in the South Indian Ocean

(2) To use the data in the assessment of atmospheric modeling accuracy

(3) To study the practical and logistical problems in the deployment of free-floating buoys from ships of opportunity and to obtain information on buoy trajectories as a basis for planning buoy release points for continuous coverage of the South Indian and Southern Pacific Oceans between 60° and 150° east longitude

This was a pilot program in preparation for an operational deployment of about 50 buoys as the contribution of the Australian Government to the first GARP global experiment drifting buoy system.

The 105-kg hull of the buoy consisted of a 5.3-m-long fiberglass-covered polyvinyl chloride (PVC) tubular spar with a polystyrene foam-filled flotation collar. (See fig. 8.) This design, with improvements, had been used successfully to carry instrumentation for tracking ocean currents and sea surface temperature measurements using the EOLE system and the Nimbus 6 RAMS.

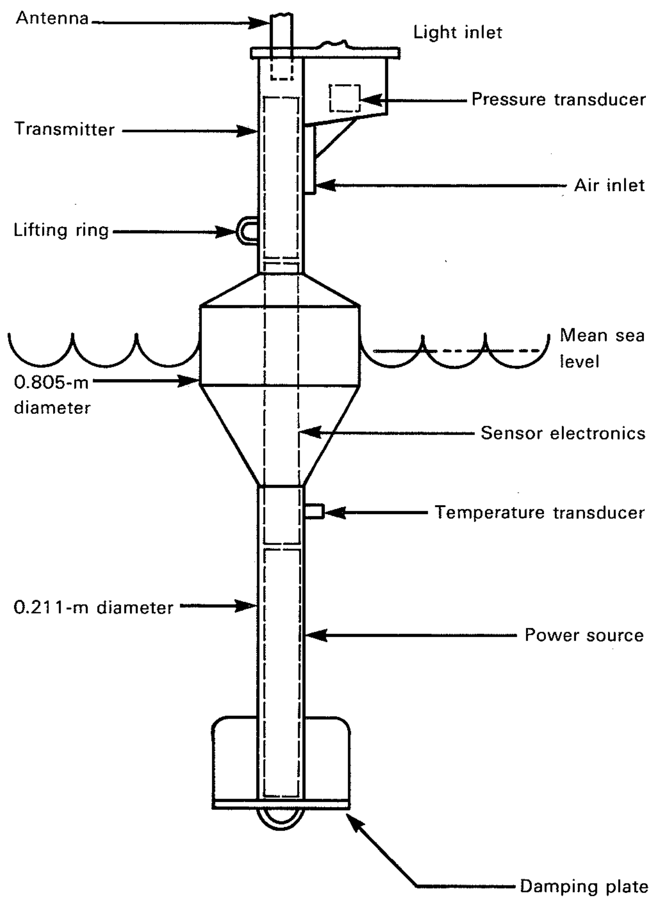


Figure 8.—Buoy physical layout.

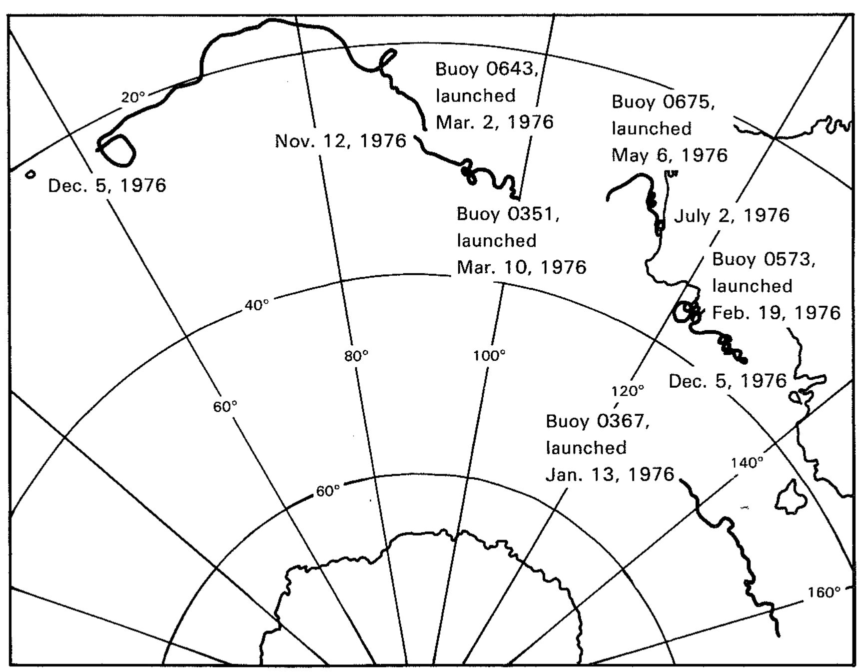


Figure 9.—Trajectories of drifting buoys as of December 5, 1976.

Table 1.—*Buoy History as of December 5, 1976*

Launch date	Buoy No.	Ship and launch position	Remarks
Jan. 13, 1976........	0367	*Thala Dan,* 49° S, 134° E	Temperature and pressure readings became unreliable after 2 weeks. It was believed to be due to prior damage sustained while at the test mooring. This buoy was tracked for 200 days to Steward Island, New Zealand (approximately 2000 n. mi).
Feb. 19, 1976	0573	*Safocean Amsterdam,* 35° S, 122° E	Operating reliably after 292 days.
Mar. 2, 1976	0643	*Safocean Amsterdam,* 27°S, 90° E	Operating reliably after 281 days.
Mar. 10, 1976	0351	*Safocean Amsterdam,* 32° S, 100° E	Ceased to operate after 247 days.
May 6, 1976	0675	*Safocean Albany,* 30° S, 108° E	Pressure readings became unreliable after 2 weeks; otherwise OK; wrecked on Western Australia coast 54 days after deployment.

Five buoys were launched during the period from January through May 1976. (See fig. 9 and table 1.) Sea pressures were measured over a range of 990 to 1037 mb, accurate to about 1 mb. Moored buoy tests before launch indicated that reliable position fixes were correct to within 5 km.

The position data were of significant value in analysis but were not usable for real-time operations because the data were not immediately available. The analysis showed that buoy data received within 6 h of real time would make significant improvement to real-time analyses in the Southern Hemisphere.

Stratospheric Monitoring With Long-Term Balloon Flights

Dr. P. Roger Williamson, *Utah State University, Experiment/User No. 35*

Chlorofluorocarbons and other chemicals released into the atmosphere may have an effect upon the stratospheric ozone layer. Recent scientific investigations led to speculation that particles precipitating into the atmosphere can produce nitric oxide (NO) and thus reduce ozone density.

This experiment employed superpressure, long-term (up to 1 yr), balloon flights at a nearly constant altitude of 95 000 ft (15 mb) to measure upper atmospheric chemistry. Long-duration flights permitted observations with a single group of instruments over a long period of time at a constant density altitude. Daily and seasonal variations then became observable. The probability of observing effects from solar events and other sporadic geophysical events was greatly increased while at the same time comparisons were made between quiet and disturbed conditions with the same instrument at constant density altitude.

The second advantage of long-duration flights over short-duration flights using zero-pressure balloons was the larger geographic coverage. Stratospheric winds carry the superpressure balloons over much greater distances and permit surveys of both latitude and longitude. Because wind systems, solar conditions, temperature/altitude profiles, and ionization rates vary greatly on a global basis, variations in the stratospheric chemistry in different geographic and geomagnetic regions are of great interest and again can be measured continuously with a single set of instruments at a constant-density altitude. The Nimbus 6 RAMS data acquisition and tracking system made the experiment possible for the first time at a reasonable cost.

Because the ion-neutral chemistry in the stratosphere is so complex and the processes so interdependent, any new knowledge of these processes can contribute to the solutions of these problems. A combination of experiments studying the various fundamental processes is required to resolve the major problems.

The normal 10-percent daily variation and 30-percent seasonal variation in ozone content make it difficult to determine long-term average change in ozone content. These variations may even have solar cycle components. Cyclical variations are a great obstacle to determining, within the next few years, the ozone-chlorofluorocarbon relationship. Recent scientific investigations indicate the NO content in the stratosphere may be produced as a result of ionization of nitrogen in the air by galactic cosmic rays and by solar cosmic rays. It is postulated that if NO is produced by ionization, then ozone is destroyed in a reaction involving NO as a catalyst; therefore, knowledge of the worldwide ionization rate and the influence of ionization events on the ozone content appear to be necessary additions to model calculations in order to relate in a meaningful way small predicted changes in ozone content to long-term measurements.

Ozone content variations induced by solar activity may be the physical process sought as a link between solar activity and the weather because ozone absorption of the ultraviolet is the major heat source in the stratosphere.

Three balloon flights were conducted with launchings from Christchurch, New Zealand, in July and August 1977. The data capability required 16 addresses for each of the balloons, giving 32 channels of 8 bits for a total of 256 bits of data every minute. For a typical satellite pass duration of 10 to 15 min, the total data capability was from 2500 to 3000 bits per pass. Each pass occurred near local noon, giving a minimum of one data readout per day. The RAMS position location accuracy was 5 km.

The instrument packages included an X-ray scintillator, a blunt probe for conductivity measurements, cesium telluride photodiodes and interference filters to measure the solar flux at 2500 and 2900 A for the ozone absorption measurements, and a visible light photocell for determining the angle of the Sun from the detectors.

Additional instrumentation included both external and payload internal temperature recorders, a NiCd battery pack recharged from a solar array, and an oscillator capacitance-type pressure sensor.

The three flights from Christchurch were preceded by a 150-mile test flight from Logan, Utah, in late April 1977. That flight showed 15 percent of the satellite-relayed data to be incorrect. The much lower data error rate encountered in the Southern Hemisphere flights was thought to be the result of a lower interference level in the 401.2-MHz frequency region used to transmit the data.

The balloons completed numerous circumnavigations of Earth and operated for several years.

Northeast Greenland Weather Data

Jorgen Taagholt, *Technical University of Denmark, Experiment/User No. 26*

The northeast Greenland weather data experiment was designed to collect data from a remote location in Greenland and to transfer weather data using the Nimbus 6 RAMS because there were no direct communication links in that area of the world.

The experiment was conducted by the Technical University of Denmark in support of the Danish Meteorological Institute. The objective was to collect data on such parameters as wind direction and velocity, air temperature and pressure, soil temperature, and relative humidity from three fixed meteorological observation stations deployed in northeast Greenland.

For this experiment, three fixed meteorological observation stations were established during the spring of 1977 in northeast Greenland. Two simple unmanned geophysical observatories (UGO's) were set up at SIRIUS Nord (81°36′ N, 16°40′ W) and at SIRIUS Daneborg (74°18′ N, 20°13′ W).

A more complex automatic weather station was also installed at SIRIUS Daneborg with the UGO station. The data collected and transmitted by these stations included wind direction and velocity, air pressure and temperature, soil temperature, relative humidity, dewpoint, and housekeeping data. The meteorological station transmitters used in the experiment were built by the A/S Lotron Elektronikk Company of Norway.

The transmitters at the stations were detected by the RAMS equipment on board the Nimbus 6 satellite and the sensor data passed on for subsequent analyses. Detailed results of the experiment findings have not been published.

Mountain Wind Project

Patrick J. Kennedy and Dr. Julian Pike, *National Center for Atmospheric Research, Experiment/User No. 24–1*

The mountain wind experiment, conducted in support of NCAR, was designed to monitor winds and other meteorological data at remote mountain locations. Information from this experiment was to be used in conjunction with the small-scale analysis and prediction project at NCAR in studying the strong and damaging downslope windstorms that afflict the lee slope of the Colorado Rockies and piedmont areas around the world. In Boulder, for example, windstorms with gusts near 100 mph occur a few times each winter. Such winds and other events of meteorological interest could be detected remotely from the mountain sites by using the Nimbus 6 RAMS. No evaluation has been made yet as to the suitability of the system for use at a remote site.

Oceanographic Experiments

The Nimbus 6 satellite mission provided a unique opportunity to conduct an extensive series of experiments in the oceans, seas, and gulfs of the world using drifting buoys. The capabilities of the RAMS on board the Nimbus 6 provided the means for obtaining data such as surface currents, temperature, deep water currents, variability of velocities and eddies, gulf stream rings, ice drift speeds, and associated meteorological parameters.

Many of the leading scientists, oceanographers, and meteorologists of the world designed important experiments using the RAMS to track drifting buoys in various bodies of water around the world. Data were obtained from buoys deployed in the Pacific, Atlantic, Arctic, and Indian Oceans; in the gulfs of Mexico, Alaska, and Japan; and in seas such as the Norwegian, Labrador, Caribbean, Tasman, Bering, and the Sargasso.

Much of the data obtained from the numerous drifting buoys or remote sensors around the world are still being analyzed. Some of the data collected has provided information to scientists heretofore unavailable by conventional data collection means, thus exemplifying the unique capabilities of satellite data collection systems.

Lagrangian Surface Current

Dr. Donald V. Hansen, *National Oceanic and Atmospheric Administration, Experiment/User No. 7*

The era around 1970 marked the earnest commencement of oceanographic measurements using lagrangian surface current techniques. Meteorologists by that time had already recognized the effectiveness of lagrangian data in describing upper air currents and the value of the data in developing theories on the dynamics of these flows. Oceanographic studies at first used ship-tracked buoys and later employed satellite-tracked platforms. Experiments using ship-tracked buoys are limited by the availability, endurance, and expense of the participating vessels. The advent of satellite-tracked drifters reduced these problems considerably. The feasibility of a satellite-buoy communications link had been demonstrated prior to Nimbus 6 RAMS in earlier experiments using the omega position location equipment system, and the interrogation, recording, and locating system (IRLS). Results from satellite-tracked drifting buoy experiments using the French satellite EOLE, which had been conducted by the National Oceanic and Atmospheric Administration (NOAA), NASA, and the French in the North Atlantic, exemplified the uniqueness and the value of lagrangian data.

Measurements of lagrangian surface currents were made by the Nimbus 6 RAMS-tracked drifting buoys deployed in various oceans as an integral part of several experiments. The areas of deployment during the 3 years following the Nimbus 6 launch in June 1975 were the Gulf of Mexico and the Caribbean and Sargasso Seas, the Gulf of Alaska and the Bering Sea, and the Equatorial/North Pacific Ocean. A description of the latter two efforts follows.

The first drifting buoy experiment was conducted for the Bureau of Land Management during the period from the fall of 1975 through 1978 as part of the Outer Continental Shelf environment assessment project. The objective was to obtain lagrangian current data for assessment of probable trajectories of accidental oil spills in the Gulf of Alaska and the southeastern Bering Sea.

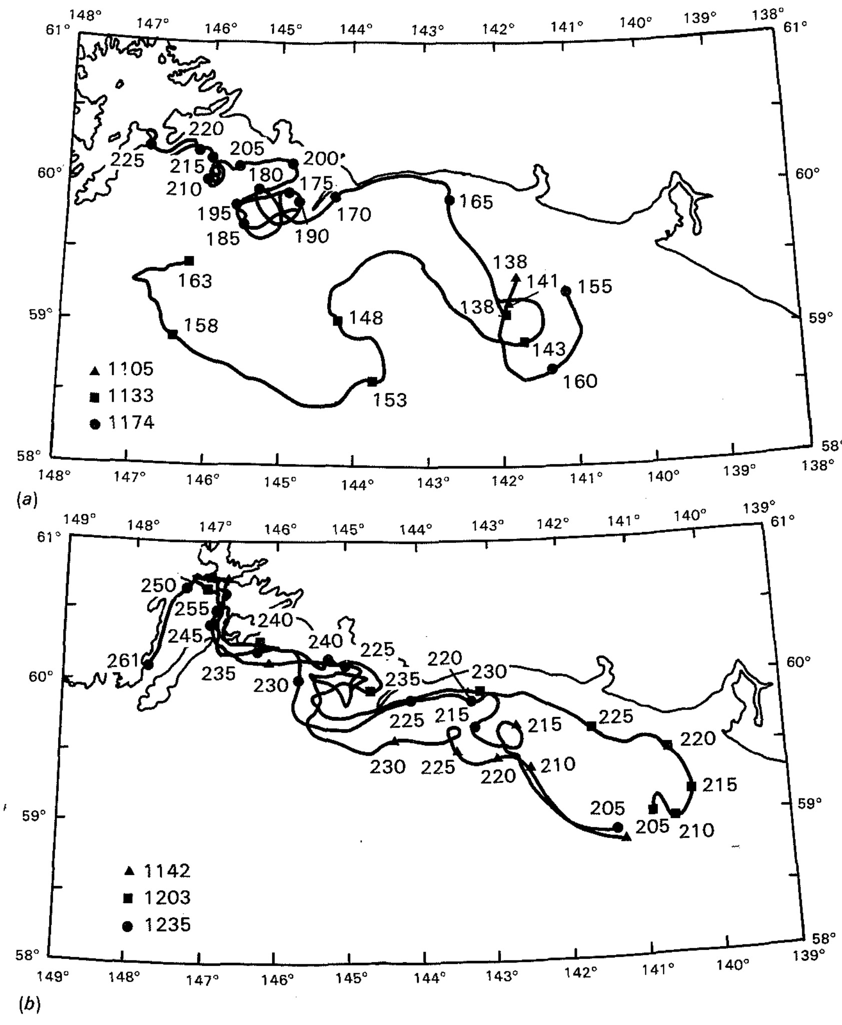


Figure 10.—Results from drift buoy deployments in the Gulf of Alaska during 1976. Numbers indicate day of year. (*a*) May and June. (*b*) July.

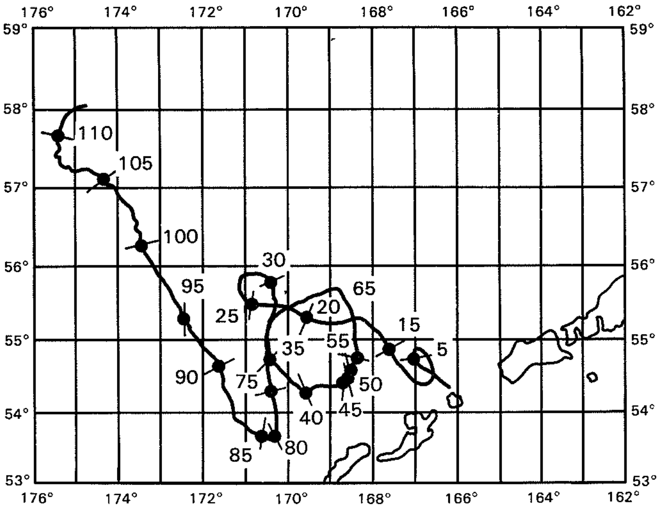


Figure 11.—Buoy ID 0544 trajectory. This buoy provides some indication that the circulation westward from the St. George Basin may be stronger and more persistent. Note the remarkable divergence of this trajectory from that of buoy 0056, which traversed the region of 54° N, 171° W, some 2 weeks later.

Initially, six NOVA University round-top drifter buoys were deployed over the Continental Shelf off Yakutat Bay. The failure rate resulting from the severe environmental conditions (three deployments, total buoy-days of data: less than 30) forced a series of design modifications to these buoys. These heavy duty buoys carried a 30-m drogue and were equipped with water temperature, wind speed, and load cell sensors. During 1976, nine of the improved design buoys were deployed, primarily in Yakutat Bay, with much greater success than the earlier models. Buoy lifetimes up to 8 months were achieved. The deployment and trajectories are shown in figures 10 to 12.

The 1976 conclusions were that, at least during summer conditions, materials released on the surface between Yakutat and Kayak Island will move generally westward at typical speeds of 10 miles per day or less. There is a pronounced tendency for movement inshore across the

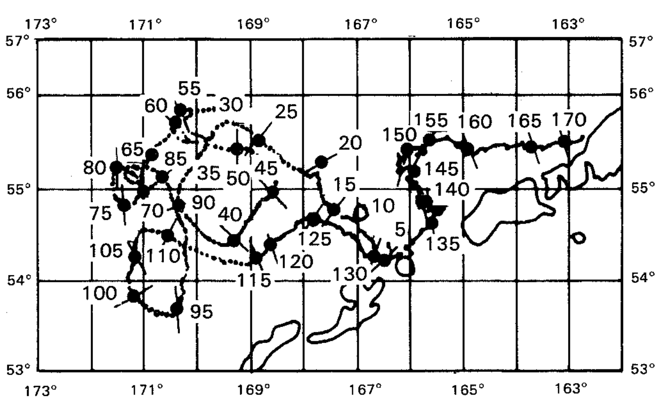


Figure 12.—Buoy ID 0056 trajectory. (Numbers indicate Julian day.)

Continental Shelf and for involvement of surface materials in an eddy west of Kayak Island, off the Cooper River. The high percentage of buoys that went ashore on the approaches to, or inside, Prince William Sound suggests these are likely impingement points for oil spilled on the surface over any part of the Outer Continental Shelf as far away as Yakutat.

The evident flow inhomogeneities in the northern Gulf of Alaska region made the original lagrangian statistical approach less attractive than anticipated. The real value turned out to be that of defining the specific spacial structures of the flow more efficiently than possible by using current meter moorings.

During 1976, the work was extended to the southeastern Bering Sea. A smaller, more economical buoy made by Polar Research Laboratory (PRL), carrying a drogue at 10 m to lessen the risk of grounding in the extensive shoal areas, was employed to obtain position data only. The three initially launched in the spring of 1976 had no drogue loss sensors, but later recovery by fishermen showed that all had lost their drogues, causing some problems in interpreting the data.

Six additional buoys were deployed in May 1977 in two lines across the continental slope of the St. George Basin. These functioned well with an average life of 153 days and displayed extensive eddy motion with only very weak net current displacements.

Lagrangian data collected by this project, by North Pacific experiment (NORPAX) investigators and by large-scale lagrangian model simulation by scientists at the Hawaii Institute of Geophysics, indicate that the northern Gulf of Alaska may be an accumulation point for surface materials.

The second lagrangian current measurements experiment was funded in part by the National Science Foundation, Office of the International Decade of Ocean Exploration, as a component of the test shuttle project of the NORPAX equatorial program. (The overall NORPAX program is managed by the Scripps Institution of Oceanography, La Jolla, Calif. The test shuttle project was a pilot program conducted during the winter of 1977–78 to evaluate the utility of a meridional "shuttle" between Hawaii and Tahiti as a preliminary effort to the design of a more ambitious shuttle operation to be conducted in the tropical Pacific Ocean during the field work phase of the first GARP global experiment in 1978–79.

The objectives were as follows:

(1) To determine the proper mix of observational methods to study the low-frequency dynamics of the equatorial circulation

(2) To determine the relations between observed and geostrophic transports, sea level, and the topography of the thermocline

(3) To determine the time scales of the flow field and of the structure in relation to the space scales

(4) To investigate the feasibility of using indices of current strength such as sea level differences for continuous monitoring

The lagrangian drift buoy project addressed all of these objectives in concert with more conventional observations. Fourteen buoys were deployed in late 1977 and early 1978 at the 150° W at various latitudes between 10° N and 10° S.

Those buoys launched by another experimenter north of 10° N latitude in North Equatorial Current (NEC) moved westward as expected, but with considerable eddying. Between 0° and about 10° N, buoys moved westward in the South Equatorial Current (SEC) and eastward in the North Equatorial Countercurrent (NECC) as expected, but in addition moved northward presumably with the near surface Eckman transport from the SEC into and through the NECC. It is interesting to note that this northward movement is in opposition to the meridional geostrophic flow.

One of the buoys deployed in the equatorial Pacific (1977) reported for over 450 days. Three deployed in 1978 crossed the central Pacific at high speed (2 knots) and ended up in the vicinity of New Guinea.

Tracking the Kuroshio

Dr. A. D. Kirwan, Jr., *Texas A&M University, Experiment/User No. 27–2*

Scientists of the College of Geosciences at the Texas A&M University, the Japan Hydrographic Department, and the Ocean Research Institute of the University of Tokyo initiated a study in 1977 using the Nimbus 6 RAMS techniques to track one of the major Western Boundary Currents, called the Kuroshio.

The Kuroshio has long been an object of intense study and is quite similar to the Gulf Stream with one major difference. The Gulf Stream has only one preferred path as it flows along the eastern seaboard of the United States, but in the region south of the main island of Honshu, the Kuroshio follows one of two possible paths. One path follows quite closely the coastline of Honshu as seen in figure 13. In the other, a large meander develops south of Honshu. (See fig. 14.) This meander is believed to extend as far south as 30° N or about 300 km from the other path.

When the Kuroshio is in its meander mode, cold water mass develops between the meander mode and the coastline. South of the meander, a warm core eddy is believed to exist. This meander circulates some of the Kuroshio water with the subtropical countercurrent system and perhaps the Kuroshio itself south of Kyushu.

Because the strong currents of the Kuroshio have such a significant effect upon the shipping industry, and the intrusion of the cold water mass greatly affects the fishing industry and weather over the northern part of Honshu, Japan expends a considerable effort in monitoring the Kuroshio.

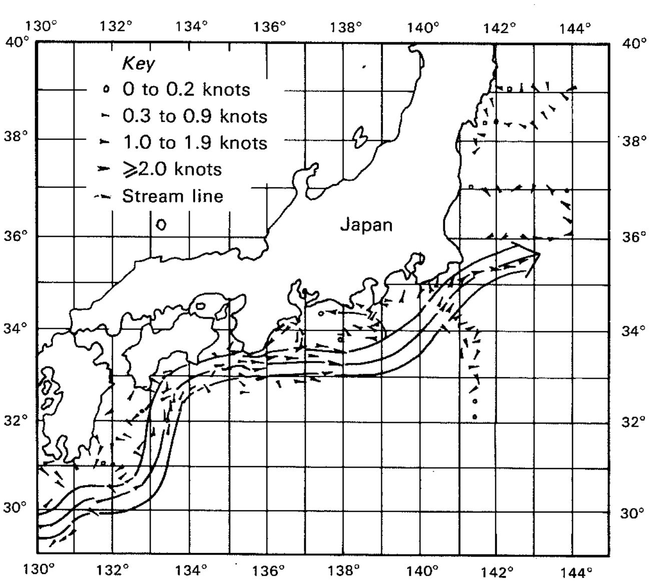


Figure 13.—Coastline path of the Kuroshio current.

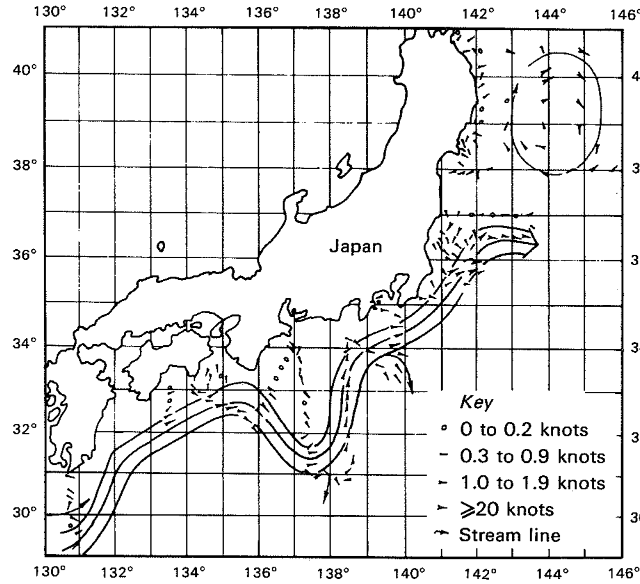


Figure 14.—Meander path of the Kuroshio current.

Because of previous United States success in tracking the Gulf Stream by the Nimbus 6 RAMS satellite, the Japanese were anxious to test these techniques with the Kuroshio.

Four drifters were deployed that drogued at 100 m by a 9.2-m personnel parachute off the island of Kyushu. The deployments were made from the vessel *Takuyo*, which was made available by the Hydrographic Department of the Marine Safety Agency of Japan. The drifters were tracked by the RAMS. The tracks are shown in figure 15.

This pilot experiment had several goals:

(1) To compare the results of the drifter tracks and velocities with those obtained in other studies and in the hydrographic surveys

(2) To verify the existence of the cold and warm water eddies

(3) To study the variability of the currents in the extension region

The agreement between the trajectories and the hydrographic surveys was excellent. The main features of the Kuroshio, such as path and velocity, were duplicated in both the drifter and survey data sets. The trajectories, however, failed to detect either the warm or cold-core eddies associated with the meander.

From the standpoint of the U.S. Navy, one of the most significant results was the demonstration of a nearly real-

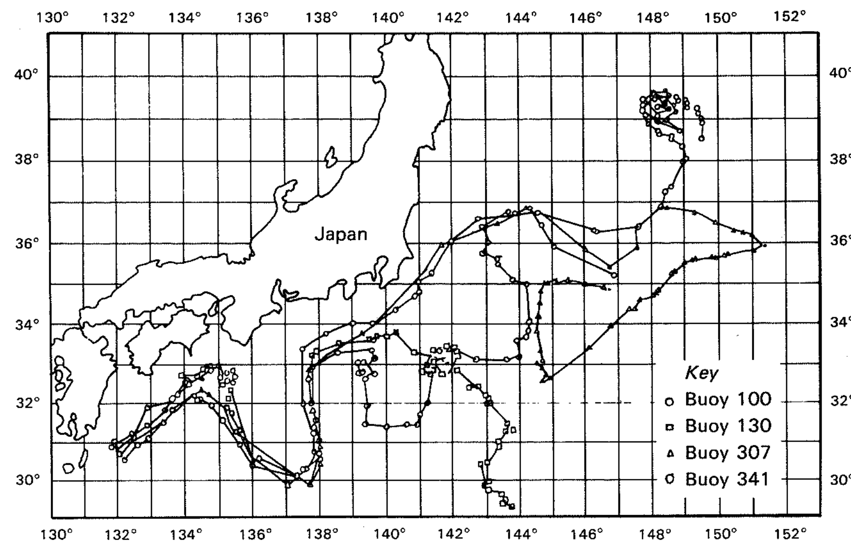


Figure 15.—Summary of drifter trajectories from time of deployment to Julian Day 110 of 1977.

time data return capability provided by Nimbus 6. The Nimbus 6 RAMS had the capability of returning not only position but environmental data as well. The transmit terminal electronics are very reliable and draw very low power so that long-term, remote, and inexpensive sensing capability is possible now for operational use by the fleet.

Mesoscale Ocean Variability

Dr. John Garrett, *Environment Canada, Experiment/User No. 30*

One of the problems associated with designing an observational grid for global numerical weather forecasting is that of determining the uncertainty associated with estimating representative values of oceanic variables for a region based upon observations at a single point. Economic and atmospheric considerations suggest that a grid spacing of about 500 km would be acceptable, but little information is available on the variability of oceanic quantities on scales smaller than this and for times of a month or longer. Because many storms affecting the oceanic upper layer are smaller than 500 km, and because recent measurements of the horizontal diffusion in the mixed layer under smaller scales using the EOLE satellite suggest that small-scale oceanic features may persist for a considerable period, the question of the horizontal extent of the area influenced by individual storms is of considerable importance at this time. A mesoscale ocean variability experiment using the Nimbus 6 RAMS was conducted in support of Environment Canada to determine the horizontal extent of oceanic variables influenced by individual storms. This experiment investigated, by means of 10 drifting buoys, the horizontal variability of velocities and temperatures in the upper layer of the ocean, at scales of 100 to 500 km, in a region expected to be stormy during the period of the experiment. (See table 2.)

The experiment consisted of placing 10 drifting buoys in a square grid with about 100 km between the buoys and with the northern edge of the grid initially along 50° N latitude and the western edge initially along 160° W longitude. This array was expected to move more or less due east at speeds between 10 and 20 km/day, remaining more or less intact until it came within 300 to 400 km of the North American coast, where it would deform, most of it going north. The area and time were chosen to provide a maximum wind stress but a climatologically small wind stress curl, so that the divergence of the surface layer should theoretically be small, which would prevent the array from spreading out too rapidly. Also the northern edge of the array should pass close to an ocean station so that comparison of conditions at the time of the experiment to the oceanographic time series maintained there should provide some good data for analysis.

The buoys were designed to drift with the motion of the upper 10 m of the water column, with the effects of the wind drag on the superstructure minimized.

The experiment was designed to accumulate data to enable the determination of the horizontal variability of temperature and velocity at scales of 100 to 500 km, and the effect of various averaging times on this variability. Another objective was to study the effect of individual storms on the motion and heat content of the upper layer of the ocean.

Table 2.—*Buoy Sensors and Characteristics*

Variable	Range	Resolution
Air temperature, °C	2.0 to 14.8	0.1
Sea temperature (average), °C	2.0 to 14.8	0.1
Air pressure, mb	940 to 1068	1
Buoy heading (magnetic compass), deg	—	2.8

Two types of analysis were performed in keeping with the two design objectives. One was description and event oriented, aimed at simply describing as fully as possible the effects of storms or other events. The second type of analysis was statistical and included space correlations computed on average over various periods.

In addition to the 10 buoys used for the ocean variability experiment, 30 prototype buoys of the type to be used during the first GARP global experiment were tested to determine buoy reliability.

No results have been reported on the ocean variability portion of the experiment.

The prototype buoy reliability experiment results indicated that of nine buoys deployed in the Southern Hemisphere during 1977, all worked perfectly.

Nine prototype buoys manufactured by Hermes Electronic, Ltd., of Nova Scotia, Canada, were deployed during the first quarter of 1977. These buoys all measure sea surface temperature, internal temperature, battery voltage and barometric pressure. By the end of the second quarter, 20 buoys had been deployed and a short time later 3 of the 20 had failed. One of the failures was due to a leak in the hull while another was an electronics failure. The third failure was almost certainly due to the buoy having been picked up by a ship and opened.

An analysis of the atmospheric measurements reported by the buoys was made. The purpose of the analysis was to review the sources of error or uncertainty in such pressure measurements. The conclusion of the analysis was that barometric pressure measurements can be made from small buoys with accuracies of about ±1 mb under typical conditions. To achieve these accuracies, it is necessary to insure that the pressure port excludes as much as possible of the dynamic pressure, preferably 90 percent or more, and to use transducers with minimum drift and temperature sensitivity. To achieve uncertainties less than 2.0 mb under extreme conditions, it is probably necessary to average the transducer signal over several wave periods. Although it is clear that some methods of processing the transmitted signal are better than others, the differences are small compared with the uncertainties arising from the transducer drift and temperature sensitivity.

Surface Drifter Buoys in the Davis Strait

Michel Metge, Kelvin N. Wood, and L. G. Spedding, *Esso Resources Canada, Ltd., Experiment/User No. 14*

Faced with the need to acquire a better knowledge of ocean surface currents in the Davis Strait area of the Labrador Sea, and particularly at the mouth of the Hudson Strait, Imperial Oil Ltd. (Canada) developed a Nimbus 6 RAMS experiment to monitor the currents in this area. An understanding of the movements of the surface currents was essential for an evaluation of the probable fate of floating oil in the event of an oil spill or oil well blowout. The knowledge gained from this experiment could be used for assessing the environmental impact of an oil spill and for planning cleanup strategy.

The experiment consisted of using the Nimbus 6 RAMS system to track drifting buoys in the Davis Strait, Labrador Sea. The plan was to release two sets of four satellite-positioned drifter buoys, at strategic locations, three times during the experiment (for a total of 24 buoys). Each time, four drifter buoys were to be deployed in an east/west line across the northern part of the area of interest, and four buoys were to be deployed in the Hudson Strait to obtain data on the in-and-out flowing currents. Fifteen-foot deep drogues were to be used in some instances to eliminate the wind-induced portion of the surface current. The buoys were obtained from Hermes Electronics Ltd. of Nova Scotia.

Thirteen buoys were deployed in the Davis Strait. One buoy was deployed with no drogue and 12 were deployed with large shallow drogues (2.3 by 7.6 by 3 m deep).

Four of the buoys survived through February 1978, the others stopped transmitting for various reasons. One beached itself, two were presumably crushed by ice, two ran out of battery power, and the other four failed for unknown reasons.

The results obtained were invaluable in helping Imperial Oil Ltd. define the surface currents of the remote Davis Strait area. The data were used to predict the probable path of potential oil spills.

Lagrangian Drift Measurements of Sea Surface Currents and Iceberg Tracking

Capt. E. A. Delaney and Capt. K. M. Palfrey, *U.S. Coast Guard, Experiment/User No. 39*

Lagrangian drift measurements of sea surface currents were conducted for the search and rescue and international ice U.S. Coast Guard project using the Nimbus 6 RAMS. These projects are supported by the 22-nation International Ice Patrol.

The first project entailed tracking drogued buoys (figs. 16 and 17) for approximately 10 days in the U.S. East Coast Continental Shelf waters between Delaware Bay and Cape Hatteras in February 1976. The resulting drift values were used to check a numerical model that had been developed at the U.S. Coast Guard Oceanographic Unit for predicting surface currents on the Continental Shelf. This surface current prediction model provides an important input to the computer-assisted solution to search and rescue cases.

The second project conducted in May and June of 1976 concerned the tracking of drogued buoys on the Grand Banks of Newfoundland for the U.S. Coast Guard's International Ice Patrol. Here, lagrangian drift velocities were measured in or near the Labrador Current. The direct surface current measurements obtained in this manner could be used to test and evaluate several iceberg drift prediction numerical models that were then in use or proposed for use by the Commander, International Ice Patrol, who has the operational responsibility for warning mariners of the iceberg hazard to trans-Atlantic shipping. In both cases, the drogued buoys were to be deployed (and preferably recovered) by Coast Guard cutters conducting oceanographic surveys in those areas.

Initially, three NOVA University drogued buoys were procured. One was launched off the Delaware coast in February 1976, in connection with the search and rescue project, but the experiment was terminated one day later.

This buoy was recovered and deployed April 4, 1976, in the Labrador Current in connection with the International Ice Patrol mission at 46°59.2′ N, 47°15.1′ W. This buoy moved with the current until April 13, 1979, when its battery power dropped and transmission ceased. Transmissions resumed on April 14, 1979, when it entered the warmer North Atlantic Current, indicating the buoy was perhaps water-temperature sensitive. Drift data obtained from this buoy were relayed to the Commander, International Ice Patrol, allowing him to better evaluate other types of oceanographic data. Following the field studies in the area of the Ice Patrol, the lagrangian drift velocities gleaned from the Nimbus 6 RAMS were used to test a numerical model of time-dependent Ekman wind-generated currents.

The results indicated that an operation involving several drifting buoys would provide a much improved ocean cur-

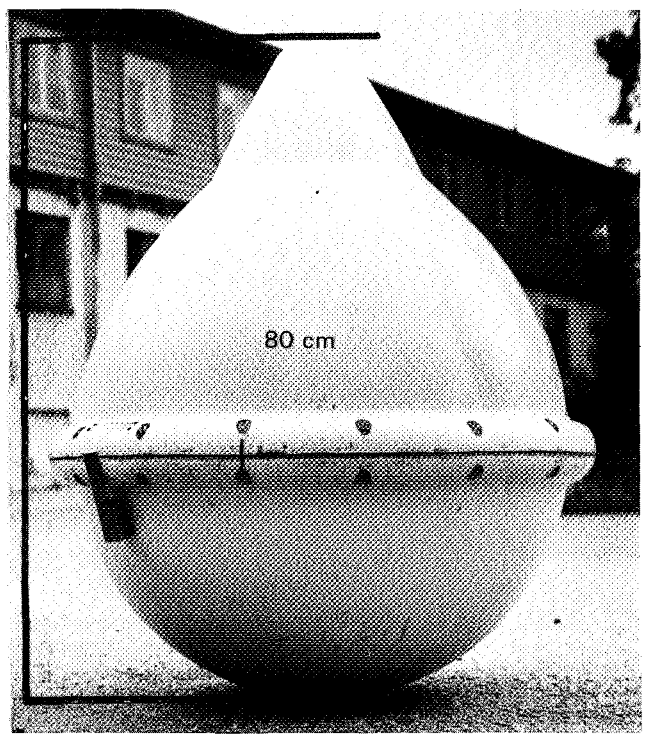


Figure 16.—Exterior view of the buoy used in the experiment. Note the magnetic switch.

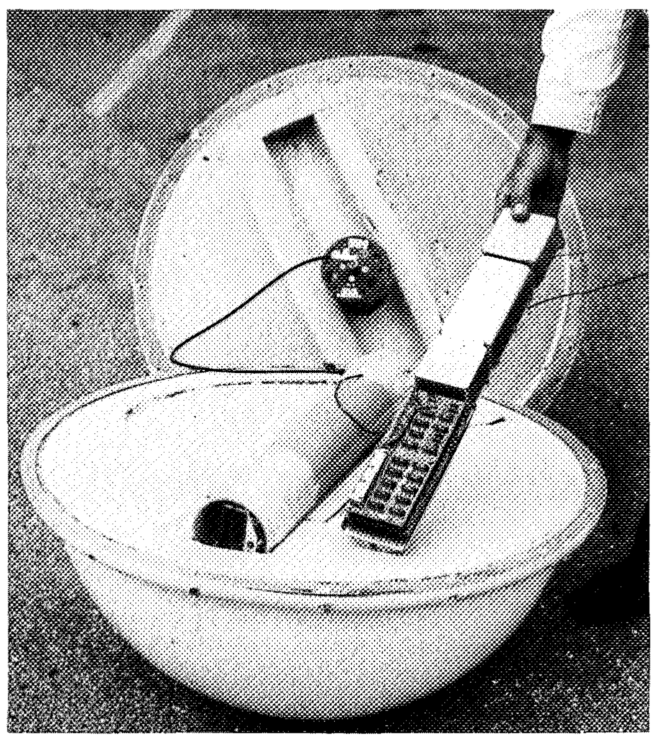


Figure 17.—The inside of the buoy of Figure 16 showing antenna, transmitter, and battery package.

rent model for use in predicting the path of drifting icebergs.

For the 1977 International Ice Patrol, it was decided to use the Polar Research Laboratory air droppable RAMS buoys deployed from C–130 aircraft onto icebergs that break off from Greenland glaciers and drift into the North Atlantic shipping lanes. This program was continued into the 1978 Ice Patrol Season. No specific data are available.

Indian Ocean and Tasman Sea

Dr. George Cresswell, *Commonwealth Scientific and Industrial Research Organization, Experiment/User No. 18*

Indian Ocean

The Division of Fisheries and Oceanography of Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) developed an experiment to use drifting buoys tracked by the Nimbus 6 RAMS to increase knowledge of the currents of the eastern Indian Ocean and thereby gain some insight into the migration of the planktonic larvae of the commercially important rock lobster. The larvae can be found hundreds of kilometers from their summer spawning areas on the Western Australia Continental Shelf. Advanced stage larvae reappear at the shelf edge roughly 10 months after spawning. The question under study was whether the ocean circulation provides a migration circuit for the larvae or is this a matter of chance.

No clear migration circuit was apparent; there was slight evidence for a clockwise gyre 1000 km across, but this was masked by mesoscale eddies 200 km across that trapped buoys (and water and larvae) for up to 2 months. Even more apparent than the gyre were the losses from it, both to the SEC and to a current flowing southward near the continent.

The latter flow, an intrusion of warm low salinity water having its origin in the tropics and occurring preferentially in autumn and winter, is well known. Because it pivots at Cape Leeuwin, it was named the Leeuwin Current. Figure 18 shows six buoys being influenced by the Leeuwin Current and associated eddies. During the autumn-winter period of 1976, seven eddies seaward were made apparent by the buoy motions. The March 23 to June 3 period in the figure shows buoy tracks.

The Leeuwin Current could be seen to be essentially continuous over 1300 km and to have predominantly cyclonic eddies seaward of it. Eddy 7 in figure 18 was the anticyclonic exception. Buoys were found to interchange between the Leeuwin Current and the cyclonic eddies. The entry of a buoy from an eddy into the Leeuwin Current was associated with a temperature step increase of

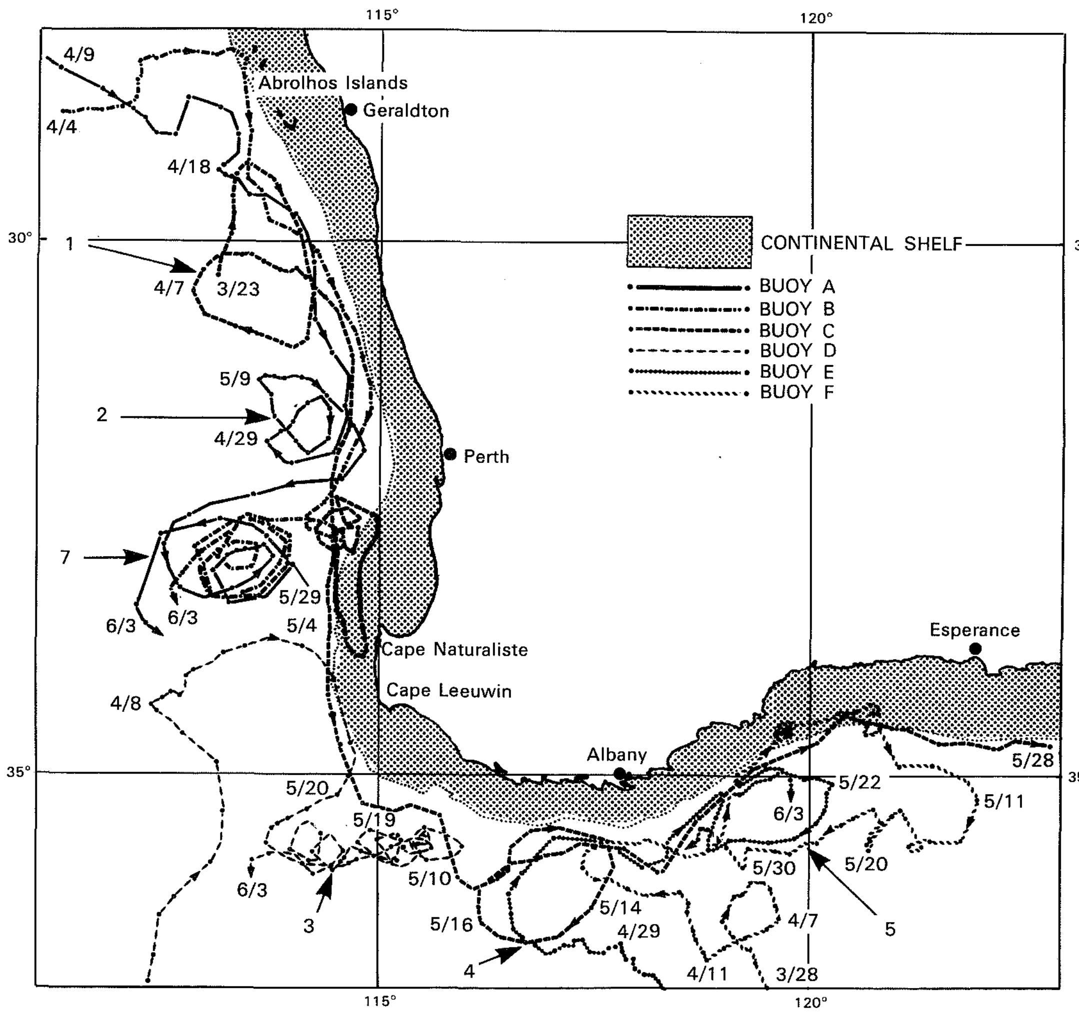


Figure 18.—Observations of a south-flowing current in the southeastern Indian Ocean. Six buoys were influenced by the Leeuwin current or its associated cyclonic eddies (numbers 1 to 5) or the anticyclonic eddy (7) during the period March 23 to June 3, 1976. The dots on the track give approximate noon positions. (Cyclonic eddy number 6 appeared in July.)

up to 3° C and an acceleration of 0.5 m·s^{-1}. Conversely, the departure of a buoy from the Leeuwin Current into an eddy was associated with temperature and speed decreases. The buoys showed that as the Leeuwin Current neared the continental slope off Cape Naturaliste it accelerated southward. Two buoys that traveled between capes Naturaliste and Leeuwin at the same time revealed a shear in the Leeuwin Current with the buoy nearer the shelf edge traveling faster than the one farther offshore. Buoys passing between these capes on four occasions traced out a region 20 km wide where they were carried southward.

From ship data gathered during the buoy experiment, it was found that the Leeuwin Current could flow at times other than during autumn and winter. If it flowed unseasonally in spring, then it would effectively constitute a barrier to circulation further west, tending to return advanced stage lobster larvae to the continent.

Other outcomes from the Indian Ocean buoy work included differences between on- and off-shelf circulation; the structure of the subtropical convergence south of Western Australia, and the currents in the northern Mozambique Channel.

In 1973, K. Wyrtki described a narrow jetlike current that flows eastward along the Equator at speeds up to 4 knots during the transition periods April/May and September/October, between the two monsoons. It was decided to evaluate this current in May 1980 using the Nimbus 6 RAMS satellite. Three CSIRO "torpedo" buoys with window-blind drogues (2 by 5 m; center depth, 12 m) were released at 58.5°, 54.5°, and 50.5° E on May 12, 14, and 17, 1980. (See fig. 19.) The buoys were tracked by Nimbus 6 and, although there were data gaps of several days and otherwise only an average of 1.6 fixes per day, the resulting data set is quite interesting.

The tracks of the buoys and their speeds show eastward motion greater than 1 knot until the second half of June. After that, buoy 1710 reversed direction to move westward; buoy 1676 failed on June 21; and buoy 1546 slowed and finally ceased moving eastward from about July 11. Initially there was evidence for a wavelength of about 500 km and an amplitude of 50 to 100 km. All buoys showed an increase of speed up to 1.7 to 2.3 knots in the vicinity of 65° to 70° E; i.e., when passing over the Carlsberg Ridge. The Maldive Islands at 73° E appeared to deflect buoy 1546 around their southern extremity, at which point the highest speed for the experiment, 2.7 knots, was experienced. Buoy 1676 passed through the Equatorial Channel between Huvada Atoll to the north and Addu Atoll to the south at 1.7 knots. Buoy 1710 reversed direction some 200 km west of the Maldives and recrossed the Carlsberg Ridge, once again increasing in speed to 1.7 knots. After crossing the ridge, its speed dropped to less than 1 knot.

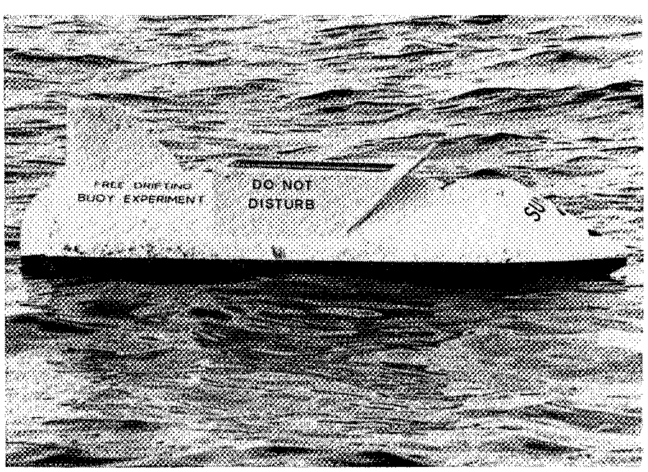


Figure 19.—CSIRO torpedo-shaped drifter.

In summary, the Wyrtki jet was observed to be well established. The jet carried the three buoys eastward at speeds greater than 1 knot until the second half of June. It appeared to speed up over the Carlsberg Ridge. The highest speed experienced was 2.7 knots by buoy 1546 as it passed to the south of the Maldive Islands.

Tasman Sea

Anticyclonic eddies are prominent in the East Australian Current system, but detailed study has been hampered by the difficulty of following a particular eddy for long periods. Because the Indian Ocean buoys had clearly indicated eddies by being trapped in them for up to 2 months, the task of tagging Tasman Sea eddies was initiated. A total of 13 buoys were used in 1977 primarily for this purpose.

Early results were spectacular in that three eddies were successfully "seeded" with two or more buoys. The tracks of these are indicated in figure 20. Of these, *A* was a preexisting eddy, the formation of *B* in March 1977 was documented by both buoy and ship observations, and *C* apparently formed in April. Although after March research vessel time was in short supply, the existence of buoys in eddy *B* enabled its evolution to be adequately followed with the limited ship time available. Eddy *B* was found to have a lifetime exceeding 1 year. At times its center moved in a counterclockwise arc, but it was generally within 50 km of 37° S, 152° E. It trapped individual buoys for 5 months. Cooling during winter resulted in the progressive deepening of its isothermal mixed layer down to 350 m. Summer heating at the surface isolated the deepest part of this isothermal layer such that the layer became a "signature" for the eddy. Pairs of buoys indicated that an annulus of the eddy rotated stiffly with periods of 7 to 10 days, but near the center the rotation period could be shorter. Similar behavior was observed in the Indian Ocean anticyclonic eddy in 1976.

With the Nimbus 6 satellite system, NASA provided the means to track and collect data from Australian drifting buoys. This has been the key to understanding two major features of the physical oceanography of Austra-

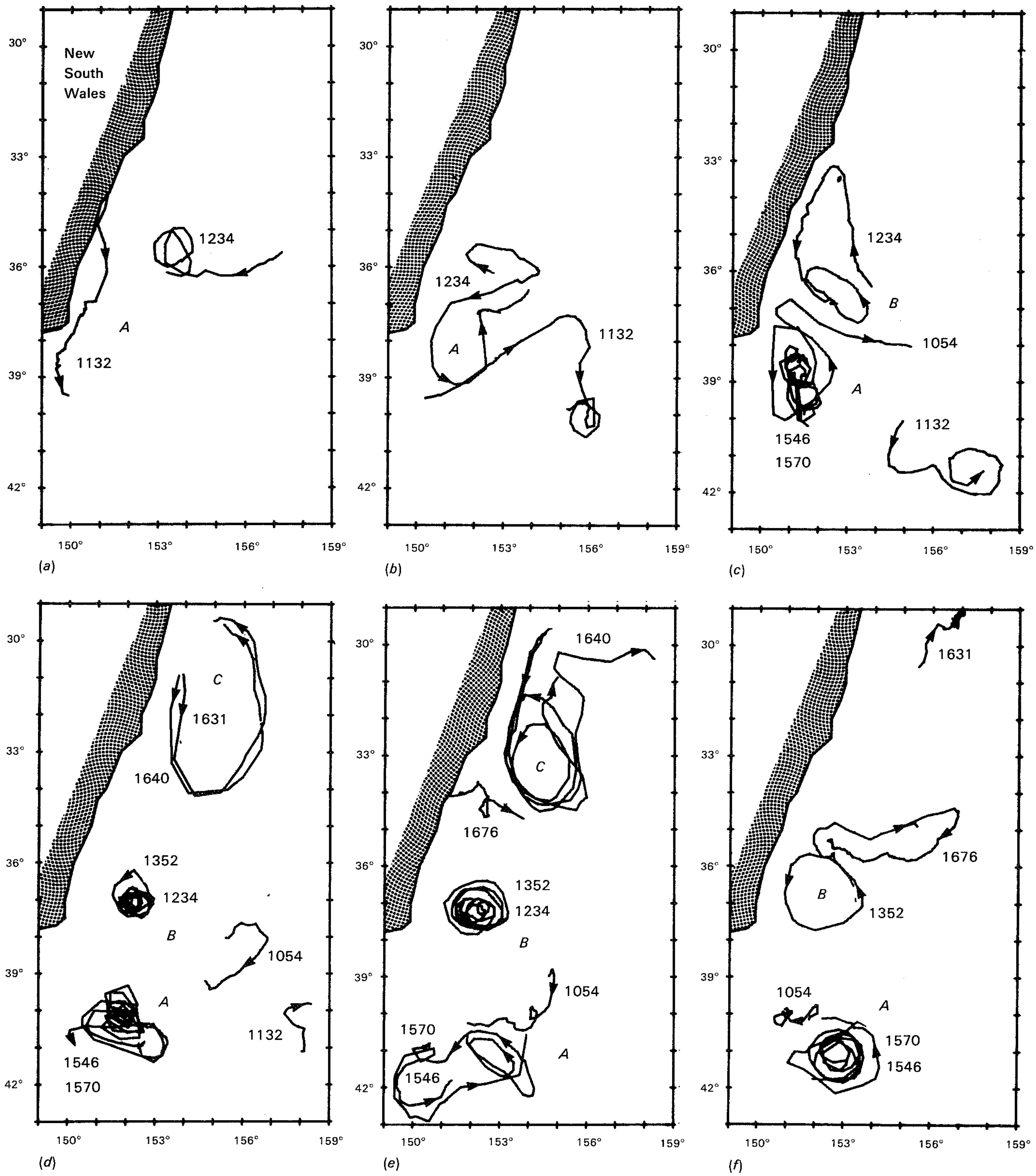


Figure 20.—Charts of buoy tracks near the eastern Australian Coast. (In the April and May charts, three eddies can be seen to exist simultaneously.) (*a*) January 1977. (*b*) February 1977. (*c*) March 1977. (*d*) April 1977. (*e*) May 1977. (*f*) June 1977.

lian waters:

(1) The nature of a warm low salinity southward current that flows preferentially near the continental slope of western Australia

(2) The formation and evolution of Tasman Sea and anticyclonic eddies

Without satellite-tracked buoys the scientific knowledge of these features would not be available.

Gulf Stream Ring Tracking Using Continental Shelf RAMS Air Deployable Buoys

Robert E. Cheney, *NASA Goddard Space Flight Center, Experiment/User No. 12*

Under the auspices of the U.S. Naval Oceanographic Office and the NASA Goddard Space Flight Center, this experiment was designed to track Gulf Stream rings, which are approximately 100-mile-diameter cyclonic vortices shed by meanders of the Gulf Stream. They represent 50 to 100-cm depressions of the sea surface and have lifetimes of up to 2 years. For this experiment several rings were tagged with Nimbus 6 RAMS satellite trackable Continental Shelf RAMS (COSRAMS) buoys to follow the rings remotely for as long as possible. Another purpose for tracking the rings was to provide ground truth data for the Seasat 1 radar altimeter, which was capable of measuring sea surface heights to a 10-cm accuracy and should be able to detect the 50 to 100-cm depressions in the sea surface containing the rings.

A rear-door transport aircraft, such as the C–130 and C–141, was used to launch the buoys. (See fig. 21.) Deployment consisted of simply lowering the rear ramp into a horizontal position and pushing the buoy out. From an altitude of 150 m, the buoy enters the water 10 s after launch. This encouraging step led to the deployment of five buoys in fall 1978. (See fig. 22.) Five cold rings were tagged.

The period of study ranged from 30 to 249 days. (See fig. 23.) Several problems were encountered but had nothing to do with the air-deployment techniques; one battery stopped transmitting. There was no evidence of deterioration, and it was suggested that the frequency of the signals might have drifted outside the allowable limit. The second problem resulted from high waves and strong currents, which caused the drogue to become unattached to the buoy for periods of time.

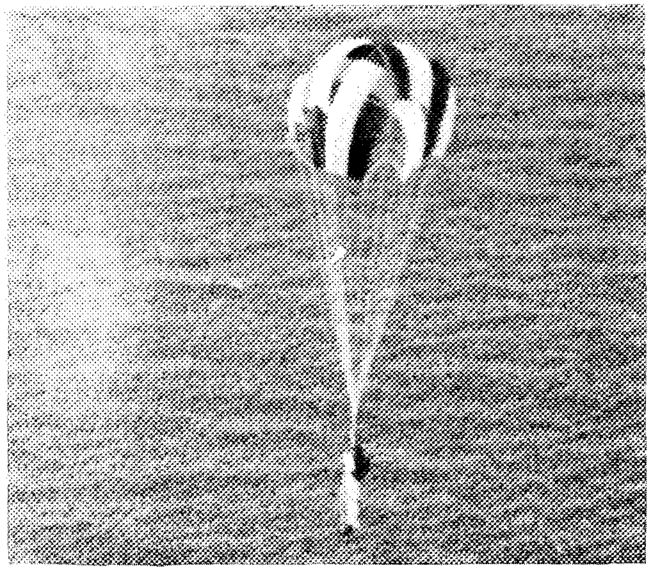


Figure 22.—8-m-diameter parachute lowering buoy into water.

Recent modifications and improvements have been made that increase the usefulness of satellite buoys. A new system, ARGOS, was launched on the TIROS N satellite in October 1978. It will provide more fixes and a greater accuracy than the RAMS system.

Data were received and processed by two independent methods: the routine Nimbus 6 RAMS operations center and the "user's terminal," which received real-time transmissions from the satellite as it passed over the COSRAMS drifters. Each drogue sensor of a buoy indicated that the

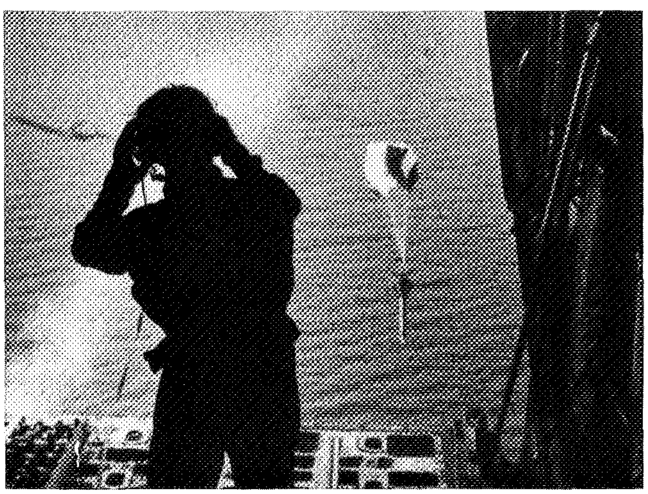


Figure 21.—Deployment of buoy from rear door of transport aircraft.

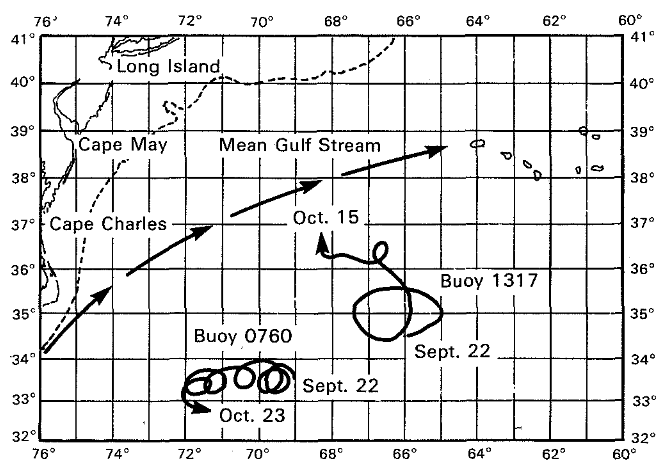


Figure 23.—Trajectories of two buoys. Both were placed near the centers of the cold rings and were drogued at a depth of 10 m. Buoy No. 0760 remained in its ring for 1 month, while No. 1317 left its ring after only 2 weeks.

drogue and tether system were deployed. The drogue sensors were equipped with a "stop" to prevent overloading and becoming stuck in the "on" position.

The COSRAMS has demonstrated that free-drifting satellite-tracked buoys can be successfully and easily deployed from a rear door aircraft. The combination of airborne bathythermograph surveys and satellite infrared images to locate Gulf Stream rings enable them to be tagged and monitored quickly and inexpensively throughout their lifetimes.

Although Seasat 1 developed a terminal short circuit in October 1978 after only 2½ months in orbit, it did manage to obtain data during several passes over the westernmost ring.

A Study of the Gulf Stream Using Satellite-Tracked Drogued Surface Buoys

Dr. Phillip L. Richardson, *Woods Hole Oceanographic Institution, Experiment/User No. 10*

A Gulf Stream experiment and a Gulf Stream ring experiment, sponsored by the Office of Naval Research and the National Science Foundation, were performed by the Woods Hole Oceanographic Institution.

The ring experiment was designed to measure the movement of rings in the Sargasso Sea to learn where rings go, what their eventual fate is, and what influences their motion. The work was one component of a cooperative and interdisciplinary experiment to study cyclonic Gulf Stream rings. Two rings were followed over their lifetimes with a series of cruises. Measurements were made of the physical, chemical, and biological characteristics of the rings and their changes with time.

Rings are formed from large Gulf Stream meanders that pinch off from the main current and form intense eddies of swiftly flowing water. During the formation of a cold core ring, a sizable mass of slope water originally locates north of the Gulf Stream and is carried south of the stream and into the Sargasso Sea. Rings are large eddies with diameters up to 300 km; they occur frequently in the northwestern Atlantic.

The purpose of the Gulf Stream experiment was to investigate the general problem of where the Gulf Stream flows and how it disperses and recirculates after passing the Grand Banks of Newfoundland. To help resolve the near-surface flow pattern of the Gulf Stream, several buoys were launched in the Gulf Stream in 1977. (See fig. 24.) In addition, many of the buoys originally launched in rings became entrained into the Gulf Stream as the rings coalesced; these buoys provided many trajectories in the Gulf Stream.

Two types of buoys were used. The first was made by NOVA University and American Electronics Laboratory (AEL). The second type of buoy was made by Polar Research Laboratory (PRL). Beginning in October 1975 six NOVA/AEL buoys were launched. In October 1976, PRL buoys were used because they were lighter, less expensive, and known to be reliable.

The PRL buoys are 3 m long, are constructed of a 0.32-cm-thick welded aluminum hull, and weigh 200 lb. The PRL buoys contained a temperature sensor located near the base of the buoy at a depth of 2 m and a drogue tension sensor. A fiberglass antenna housing is attached to the top and a flotation collar is located just below the antenna. Six PRL buoys were recovered; all were structurally sound and three of them were repowered and relaunched. The mean lifetime of the PRL buoys was 230 days. This figure includes the life of five buoys recovered at sea (mean lifetime of 300 days). Three of the PRL buoys worked for over 400 days.

During the period from October 1975 to June 1978, 31 buoys were launched in various parts of the Gulf Stream system. In mid-1977, the number of buoys that were being simultaneously tracked peaked at 17. Several very different types of trajectories reflect the different flow regimes in features such as the Gulf Stream, rings, topographic and other mesoscale eddies, and in different geographical areas such as near the mid-Atlantic ridge and in the Eastern and Western Basins of the North Atlantic.

The trajectories of the buoys in the Gulf Stream suggest three possible branches of the surface currents. One branch swings around the Southeast Newfoundland Rise and turns northeastward. From here the current divides: one part continues northeastward and the other part moves eastward across the mid-Atlantic Ridge, north of Azores, near latitude 42°/43° N. A second branch of the stream continues to flow southeastward from the main current, running along the western side of the Southeast Newfoundland Rise and crossing the mid-Atlantic Ridge south of the Azores, near latitude 33° N. The third branch consists of a southwestward flow on the south side of the Gulf Stream. Approximately one-half of the buoys moved out of the stream and into the southwestward flow; the other half continued moving eastward. The westward flow was difficult to resolve because it is dominated by highly energetic eddy motion. The energy of the eddies decreases quite rapidly with decreasing latitude.

Twenty-one buoys were launched in Gulf Stream rings as part of the interdisciplinary ring experiment. When launched near the center of a ring, these buoys tended to move radially outward toward the high velocity part of the ring and stayed there circling the ring over a 2- to 10-day period. One buoy stayed in a ring as long as 8 months and completed 86 loops.

As shown in figure 25, the movement of the center of rings is inferred from the looping motion of the buoys. The trajectories suggest that rings frequently coalesce with the Gulf Stream. Often, rings partially coalesce with the Tram and form again. Rings north of Bermuda exhibited large clockwise loops as they became attached to the stream, were advected downstream, and formed again. There is evidence of a general southwestward movement of those rings that were not touching the stream. There is also evidence for a semipermanent and complicated ring/meander structure lying along the New England Seamounts.

Three buoys were located in anticyclonic rings north of the stream. These buoys all came out of the rings and went into the stream rather quickly (typically in 1 month).

As the Gulf Stream flows eastward, it must cross over the New England Seamounts, which are an impressive mountain chain reaching quite close to the ocean surface and occupying a large portion of the deep water region.

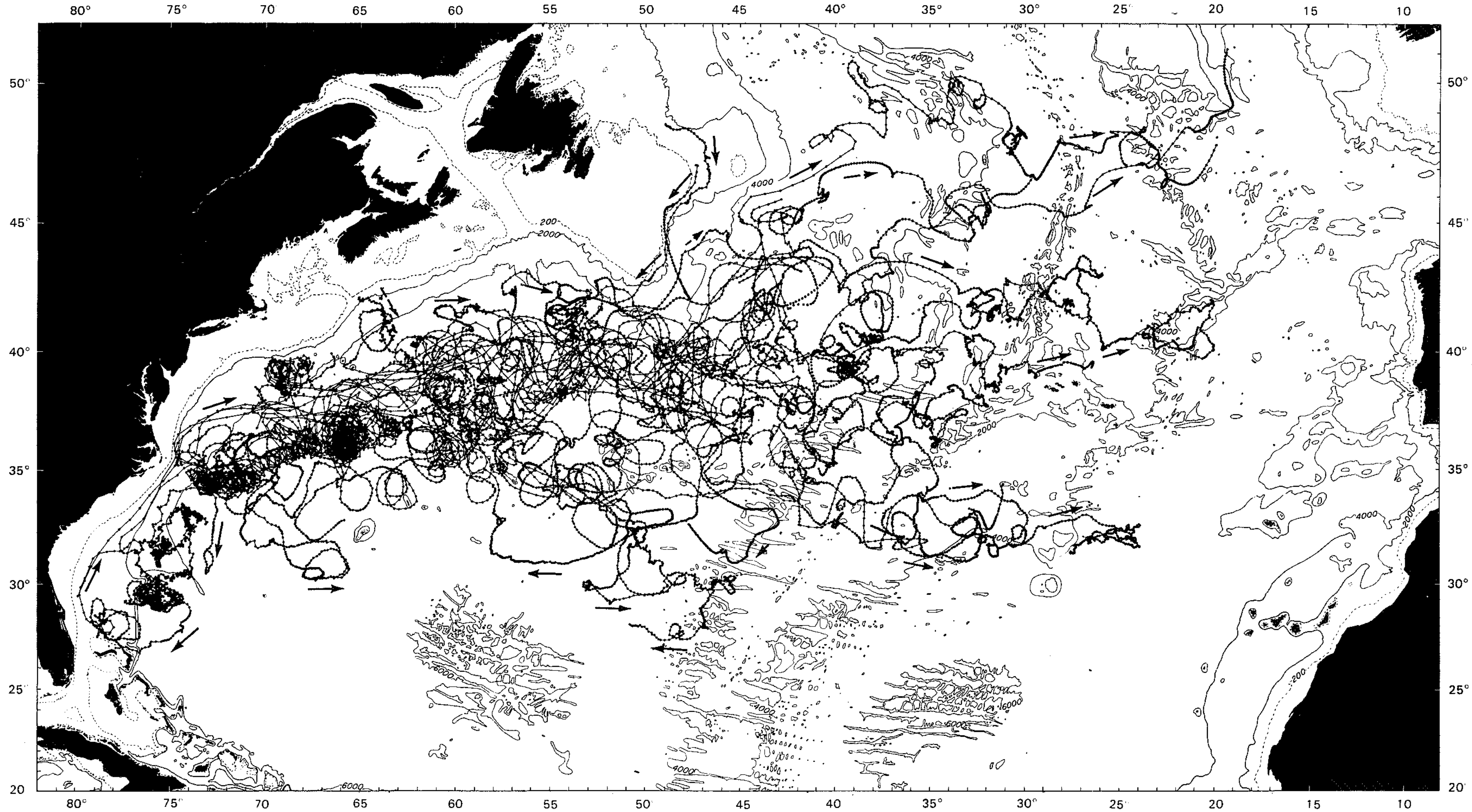


Figure 24.—Trajectories of 35 free-drifting buoys. Seven trajectories of other investigations have been added, including one highly smoothed one east of the Grand Banks. Two positions per day are shown by dots.

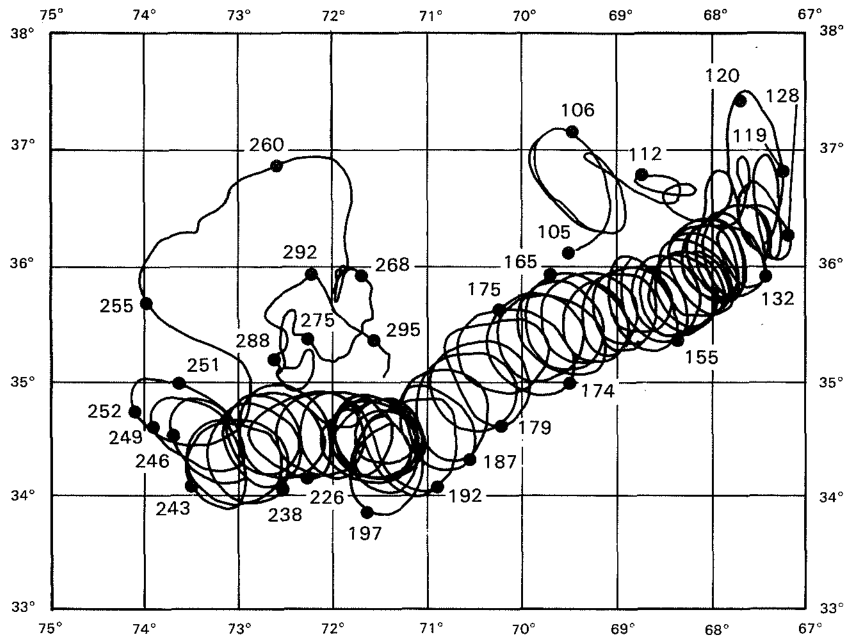


Figure 25.—Trajectory of buoy 731A, launched April 14, 1977, in ring Bob. The trajectory was calculated with a cubic spline. The numbers represent the consecutive days of the year beginning with January 1.

The deep water of the Gulf Stream must either be blocked by or pass over the seamounts or between them. Several buoys that moved eastward in the Gulf Stream showed that surface currents can be strongly influenced by individual seamounts as well as clusters of seamounts. Approximately half of the buoys in the Gulf Stream passing the New England Seamounts became trapped in a complicated meander/ring/eddy structure lying near the seamounts.

The buoys revealed some interesting aspects of the ocean flow, including the movement of rings, paths of the Gulf Stream, and the influence of bathymetric features such as seamounts on the surface flow. Although the buoy trajectories are a measurement of the near surface currents (very close to the surface, 2 m for the buoys without drogues), these currents frequently extend to great depths, at least in the case of rings and the Gulf Stream.

While buoys were in strong currents, the influence of the wind on the buoy either directly or via surface waves and wind drift currents was probably small. One buoy stayed in a ring for 8 months; the wind had little or no effect on this one, or on other buoys in rings. As the buoys moved into the eastern regions where slower currents were observed (e.g., over the Mid-Atlantic Ridge), the wind influence on buoy motion may have become important and thus these trajectories need to be interpreted with caution. The problem of wind-induced buoy velocity is under study.

RAMS Collection of Meteorological and Position Data in the Norwegian Sea

Jack Nordo and Dr. Carl Kolderup Jensen, *Det Norske Meteorologiske Institutt, Experiment/User No. 9*

The Norwegian Meteorological Institute developed an experiment using the Nimbus 6 RAMS to obtain meteorological data from remote areas of the Norwegian Sea and to determine the flow of ice in the Arctic Ocean. The meteorological data were obtained from a moored buoy in the Norwegian Sea (66° N, 02° E) and a Norwegian weathership, *M/S Polarfront,* cruising in the same area. The data were used as inputs to the World Weather Watch data base.

Telemetry units were placed on ice floes and icebergs in the Arctic Ocean and their positions were acquired through the RAMS system. Ice drifts and surface currents were tracked and the information was used to aid fishing, shipping, and oil drilling operations. During an oil well blowout in April 1977, three drifting buoys were used to track the resulting oil spill. (See fig. 26.)

The purpose of the ice drift investigations were as follows:

(1) To obtain ice drift speeds in the Svalbard-Greenland area and compare them with meteorological and oceanographical conditions. The results will be used to develop forecast rules (short range for sea ice movements).

(2) To use ice drift speeds to determine the outflow of sea ice from the Arctic Basin and from the eastern part of the Svalbard Archipelago to verify numerical models for ice circulation in the Arctic Basin.

(3) To study the tidal influence upon the ice drift and obtain average speed of sea surface currents.

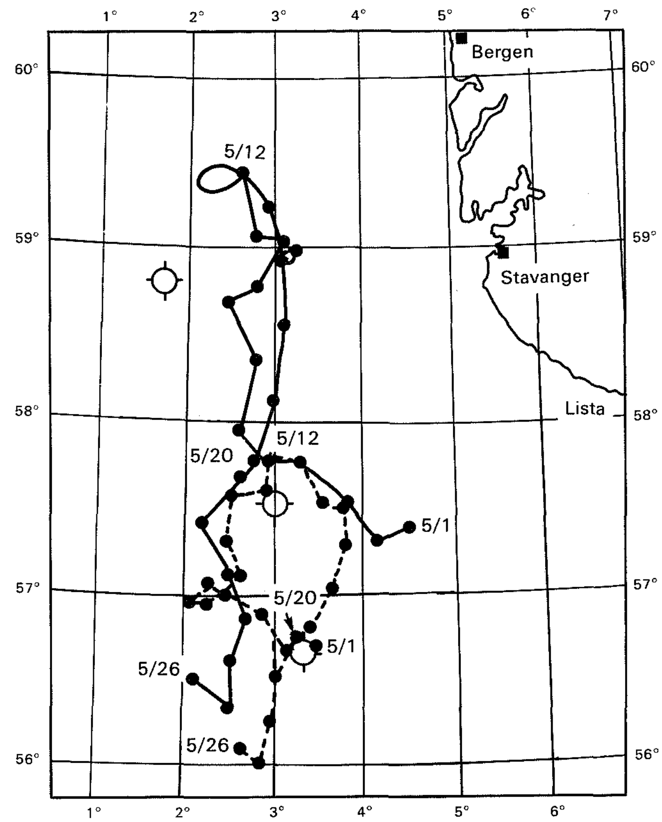


Figure 26.—Satellite-obtained positions for two buoys in the North Sea. The buoys were deployed in connection with the blowout on the *BRAVO* oil platform. The southernmost buoy was drifting at the same rate as the oil spill and became a very good indicator for the oil drift.

It is very important to develop forecasting rules for the ice movements in these ice-packed seas. The information will be used in connection with the shipping of coal from the mines of Longyearbven as well as for fishing and hunting activities, which have a long tradition in this remote area.

It is estimated that 80 to 90 percent of the drift ice that leaves the Arctic Basin passes through the Fram Strait between Spitsbergen and Greenland. In connection with the polar experiment, which is a subprogram of GARP of the World Meteorological Organization, drift speed values obtained in this area are of great interest. They may be used, for instance, to estimate the outflow of ice from the Arctic Basin, and thus serve as control for the circulation models for the drift ice in the Arctic Ocean.

The transponders used in this experiment were insulated in a case that would serve as a floating buoy after the ice disintegrated. The data obtained from the floating buoy would be used to obtain data on the surface current of the water, which is sparse in this area.

A transponder was mounted on the weathership *Polarfront II* in June 1975. It transmitted wind direction, air/sea and internal temperature, air pressure, and reference and battery voltage. These transmissions continued until July 7, 1975, at which time transmissions stopped due to battery failure. The battery was replaced on July 23, and transmissions continued until July 31, at which time circuit failure caused transmissions to cease.

A spar buoy (fig. 27) and the weathership platform were activated on October 1, 1975, with continued operation through November 11, 1976. The spar buoy was anchored in approximately 1900 m of water next to weather station M, position 66° N, 02° E in the Norwegian Sea. Data were collected from the two data platforms.

Several transponders were placed on suitable ice floes on small tabular icebergs in the eastern waters of Spitsbergen Archipelago by research vessels. Free drifting buoys were also launched in the same area as well as in the Antarctic to collect ice drift data. The position of the transponders and buoys was determined daily by Nimbus 6 RAMS, and from the data ice drift speed, ocean surface

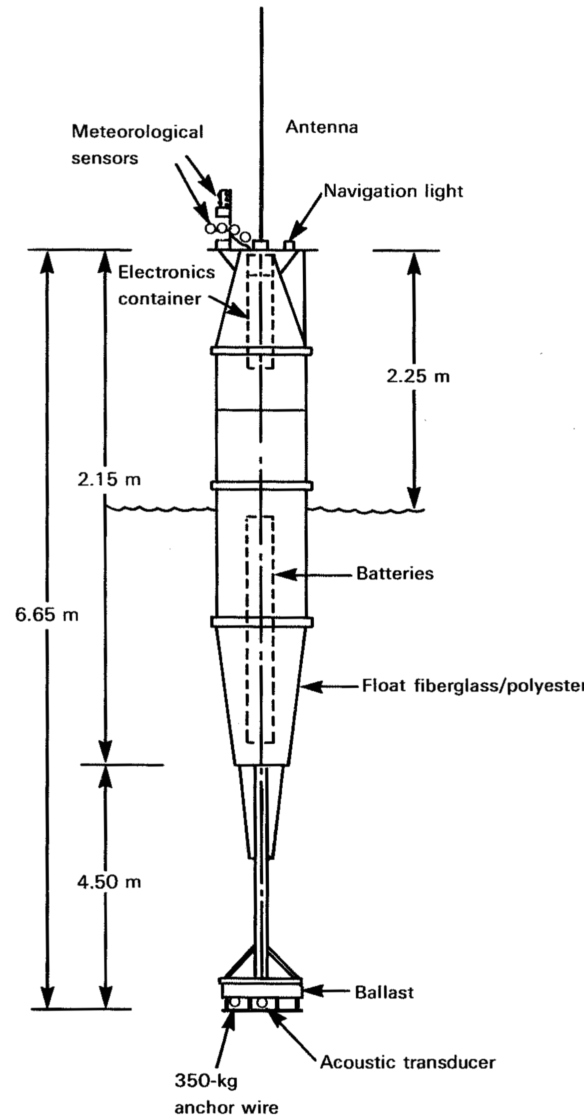


Figure 27.—Diagram of the spar buoy used in the experiment.

currents, and tidal influences on ice drift speed could be determined.

On January 23, 1977, a transponder was activated in a high mountain station in Norway (1300 m above sea level). The purpose of this experiment was to test the equipment under "arctic conditions."

During January and February four transponders were set up in the Antarctic to collect meteorological data.

In April 1977, an oil drilling platform in the North Sea experienced a blowout and subsequent oil spill. Because of the extremely serious situation, the Norwegian Meteorological Institute launched three buoys adjacent to the oil spill in hopes of tracking the spill position. (See fig. 26.) NASA agreed to track these buoys with the Nimbus 6 RAMS and provide the institute with daily position data on the buoys. Two buoys were positioned south of the oil spill and one to the north of it. Some weights were placed on the buoys to make them drift along with the oil, nevertheless it appeared that the northernmost buoy was drifting somewhat faster than the spill. The two southernmost buoys were drifting close to each other, and toward the end of May one of these buoys was recovered at the position given by the satellites. The drift of the two southernmost buoys corresponded very closely to the drift of the oil.

United Kingdom Drifting Buoy Project

Robert R. Dickson and H. W. Hill, *Ministry of Agriculture, United Kingdom, Experiment/User No. 32*

The drifting buoy experiment was a cooperative effort among four United Kingdom agencies: the Ministry of Agriculture Fisheries and Food Fisheries Laboratory, Lowestoft; the National Institute of Oceanography, Wormley; the Meteorological Office, Bracknell; and the Ministry of Defense (Navy). Three sets of experiments were planned. The first, called the Norwegian Sea bottom-drift experiments, were designed to continue investigations of the deep water circulation in the Norwegian Sea to build on and confirm the results of the 1971 EOLE experiments. Drogues were planned to be set at 1000-m depth close to the continental slope of the eastern Norwegian Sea at sites 9 and 10 (primary) plus site 11 (secondary). (See fig. 28.) The purpose was to investigate the theoretical possibility that a southgoing deep flow exists along the slope from Spitsbergen to southern Norway as part of a general anticyclonic gyre that is suspected to occupy the deeper layers of the Norwegian Sea Basin. The existence of this current is of economic importance in that it assists the migration of adult Arcto-Norwegian Cod from the Barents Sea to their spawning ground off Lofotens.

The North Atlantic deep-drift experiments were designed to investigate the basic oceanography region where the North Atlantic Drift divides into three branches, a part turning south along the western coast of Britain and Ireland, a part moving through the Faroe-Shetland Channel to the Norwegian Atlantic Current, and a part turning west to pass south of the Faroes and onward to Iceland. For this purpose, the drogues were to be set 200 to 350 m deep. Launch sites are sites 1 and 2 (primary) plus 3 and 4 (secondary) in figure 28.

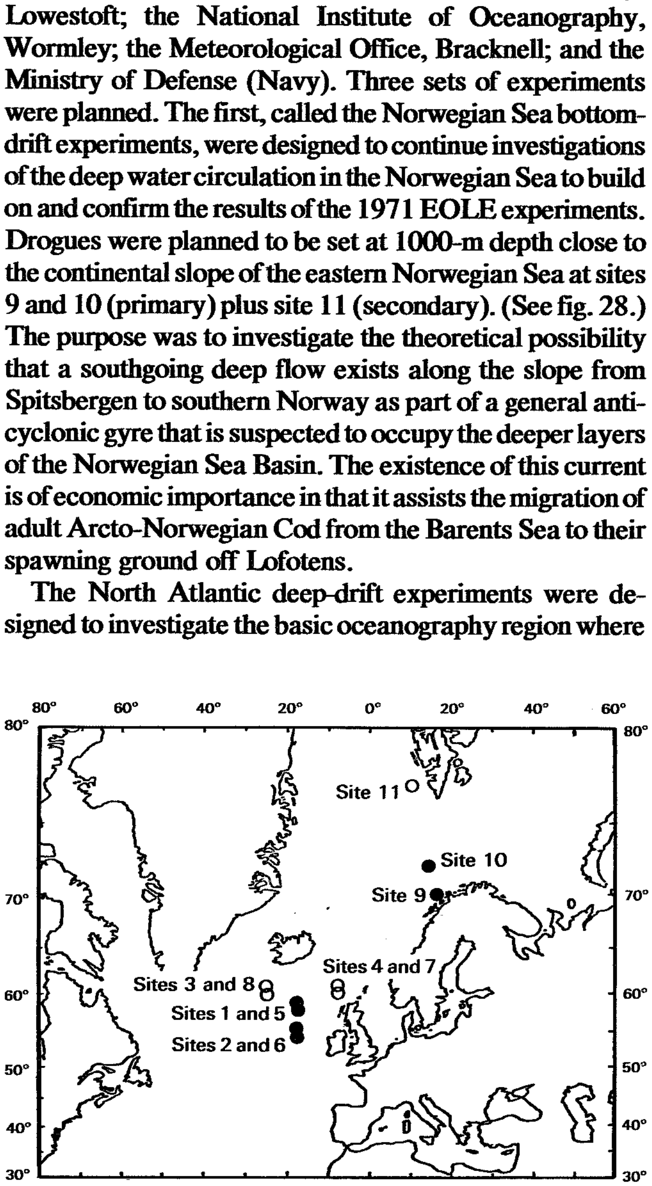


Figure 28.—North Atlantic deep-drift experiment map. Sites 1 and 5 (primary): 58°00′ N, 18°00′ W, 200- to 350- and 50-m drogues; sites 2 and 6 (primary): 55°00′ N, 18°00′ W, 200- to 350- and 50-m drogues; sites 3 and 8 (secondary): 60°00′ N, 20°00′ W, 200- to 250- and 50-m drogues; sites 4 and 7 (secondary): detailed position to be decided, 1000- and 50-m drogues; site 9 (primary): 69°45′ N, 16°00′ E, 1000-m drogue; site 10 (primary): 72°00′ N, 15°00′ E, 1000-m drogue; and site 11 (secondary): 77°00′ N, 11°30′ E, 1000-m drogue.

The third group of experiments, called wave and surface drift experiments, were primarily designed to provide surface wave data and to investigate correlation between the wave and surface current conditions from sites 5 to 8. (Statistical wave parameters were also planned to be monitored at sites 1 to 4). The resolution and recording periods of wave measurements at sites 5 to 8 was to be increased over that at sites 1 to 4. Near-surface water movements were to be monitored by means of drogues deployed to 50-m depth. Their deployment in locations close to deep drogue sites was designed to provide surface current data to correct deep drogue drift.

The design of the buoy and drogue assembly is identical to that used by the Fisheries Laboratory in Lowestoft in 1971 in the EOLE satellite Norwegian Sea buoy drift experiment. (See fig. 29.) These are 10-ft-long fiberglass spar buoys containing the transmitting antenna and waterproof housing. The electronic units and batteries in instrument compartments are sealed by seating the antenna onto a ⅛-in. thick neoprene gasket. Each buoy is equipped with a mercury battery pack with a design life of 5 months. Chain is used to ballast the buoy in an upright position. Due to the relatively large draft of the loaded spar buoy, a 63-ft flat diameter nylon cargo parachute is attached to the buoy near the center of flotation by hydrographic wire.

In operation the parachute and shrouds are bound into a parcel using ropes of tightly twisted plasticized polyvinyl alcohol film, which is soluble in sea water. The film dissolves slowly enough to insure that the parachute can be lowered to the required depth before the canopy opens. The parachute is shackled to the drogue wire via a swivel and a 100-lb weight shackled in at this junction. The drogue wire is then played out to lower the parachute to the required depth and the free end of the wire is then attached to the towing lug of the buoy via a second swivel. The buoy is deployed by using a lifting lug located near the center of gravity.

Two buoys with 1000-m drogues were released in the Norwegian Sea. One was launched at 69°45′ N, 16°06′ E, on August 24, 1975, and tracked until September 3 when it was thought that weather put it out of action. The other buoy was launched at 72°01′ N, 14°57′ E, on Septem-

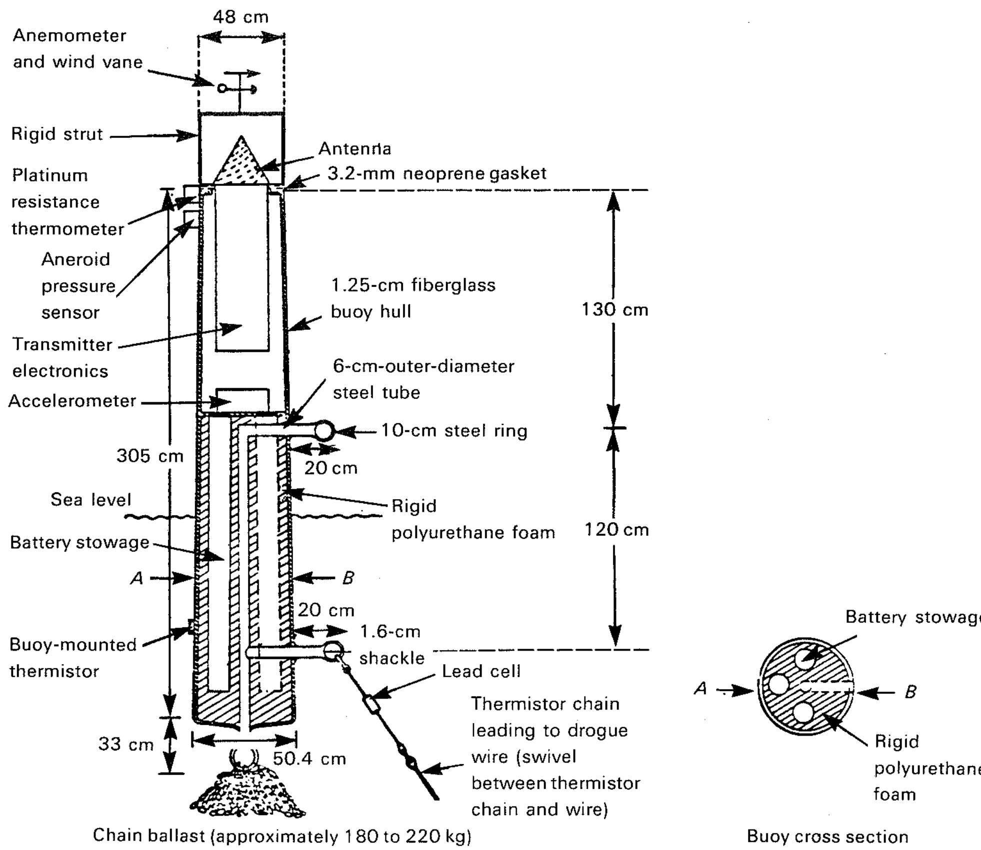


Figure 29.—Diagram of spar buoy and drogue wire attachment.

ber 5, 1975, and tracked on a northeasterly course until October 1 when it stopped transmitting at 73°05′ N, 16°0′ E. One buoy with a 50-m drogue was released west of southern Ireland at 51°58′ N, 17°22′ W, on October 1, 1975, and tracked along a southeasterly course until January 2, 1976, at 48°19′ N, 14°10′ W.

Western Boundary Eddies of the Gulf Stream

Dr. Fred M. Vukovich, *Research Triangle Institute, Experiment/User No. 43*

In recent years, an urgent need has developed to understand oceanic exchange processes between the water on the Continental Shelf and the Gulf Stream off the southeast coast of the United States. This need grew out of potential dangers to the biological, chemical, and geological systems of the nearshore environment resulting from several factors:

(1) The exchange processes at the inner edge of the Gulf Stream must be determined to specify the residence time of alien materials, such as oil spills and drilling debris, on the Continental Shelf so that the reality of the potential effects to the marine environment can be determined and adverse effects controlled.

(2) Nuclear power plants may be positioned near the Continental Shelf, and these would transfer excess energy into the coastal waters. It is important to locate these plants properly so that exchange processes at the inner edge of the Gulf Stream may effect rapid heat diffusion.

(3) The coastal states are considering ocean outfall systems to accommodate waste water discharge. To determine optimum location for ocean outfall systems, it is necessary to understand the exchange processes on or near the Continental Shelf that would influence the residence time of the pollutants on the Continental Shelf and minimize the probability of transport of the pollutants back to the coastal regions.

Eddies on the western boundary of the Gulf Stream have been observed using satellite infrared imagery. Theoretical studies suggest that free modes of barotropic Continental Shelf waves on the western boundary have upstream directed waves; but the direction can be affected by atmospheric forcing, convection by currents, and wave and instability mechanisms. It has been shown that barotropic waves that interact with the current shear of the Gulf Stream will become unstable and propagate downstream along the shelf.

Whatever the cause of the perturbations, there is need to know how far toward shore water is being drawn into the Gulf Stream and if there is a difference between the exchange processes associated with short-period eddies as opposed to long-period eddies.

A real-time oceanic study was performed using NOAA satellite data, Nimbus 6 RAMS to locate free drifting buoys, and conventional data obtained from a research vessel. NOAA satellite images were used to detect and locate eddies. The location data were used to plan an oceanic field program in which a research vessel released the Nimbus 6 RAMS buoys and collected conventional data in the eddies.

Four experiments were accomplished between the first of April and the end of May 1977. Cruise I–77 was initiated in early April but was canceled by partial equipment failure and rough seas, which precluded safe working conditions. Real-time temperature/depth data were collected along all of one and part of two and three planned transects, and one buoy was launched before the cruise was canceled. The buoy provided daily location data through the eddy and a major portion of the Gulf Stream.

Cruise II–77 was initiated April 14 in the southeastern region of Onslow Bay off the North Carolina coast. Four transects were completed and salinity/temperature/depth data were collected at 27 stations. The one free-drifting buoy launched upstream of the eddy provided daily coverage of surface currents in the vicinity of the eddy.

Cruise III–77 was initiated in mid-May 1977 southeast of Long Bay. In addition to conventional data obtained by the research vessel, drifting buoy data were obtained from two buoys, one launched within the center of the eddy and the other within the warm water region shoreward from the eddy. NOAA imagery was monitored continuously from initiation of Cruise III–77 until May 19. Cruise IV–77 was initiated on May 16–17 to study the time-dependent nature of the perturbation. Salinity/temperature/depth data were collected.

The four experiments revealed that a class of Gulf Stream Western Boundary Eddies (WBE's) developed immediately downstream (within 100 km) from an alongshore topographical feature called the Charleston Bump. The wavelength and height of the WBE's form completely in 2 or 3 days. Between 32° and 34° N, the WBE's have an average wavelength of 148 km, height of 52 km, and period of 6 days, and they move downstream at an average speed of 24 km/day. The wavelength varies from 70 to 290 km. In this region the flow is influenced by the Blake Plateau.

C. Martell and J. Allen have recently demonstrated that topographic features such as the Charleston Bump can trigger perturbations. They showed that in the presence of a current opposite in direction to the Continental Shelf wave phase velocity, waves will develop downstream from an alongshore topographical feature. Chao found that a Continental Shelf wave of a certain frequency incident on an alongshore bump will trigger all allowable modes at the same frequency with the highest mode having the largest amplitude.

Allen noted that when the wind stress had a delta function behavior in time, free Continental Shelf waves develop because of the stress and the variable topography. Steady-state motion develops over the region of variable topography and the flow follows the contours of constant depth. The horizontal scale of the forced response, a region of anticyclonic vorticity fixed over a topographic feature, and of the transient response, a region of cyclonic vorticity propagating downstream, associated with flow over an isolated topographic feature, has been shown to be identical to the horizontal scale of the topographic feature.

The WBE downstream from the Charleston Bump may be associated with upstream perturbations. It was shown that a WBE formed where there had been an isolated warmer lens shoreward of the western boundary of the Gulf Stream. In the dissipation stage, WBE's upstream from the bump forced isolated warm lenses on the shelf which drift downstream; however, the average alongshore scale of the upstream perturbations was 270 km, or nearly twice that of the downstream perturbations.

Immediately downstream from the bump, the thermal manifestation of the WBE at the surface is a wave pattern. Alternating tongues of cold and warm water are often associated with the WBE. In the subsurface, the WBE appears as a lens of cold, low-salinity, high-density water located on the shelf slope at 325 m. A dome of cold, low-salinity, high-density water projects upward to the surface. The alongshore dimension of the lens is similar to that of the temperature wave pattern at the surface.

The data indicated cyclonic motion associated with the WBE from the surface to approximately 300 m. This assessment is supported by the following:

(1) A countercurrent, relative to the Gulf Stream, existed over the shelf break on the shoreward side of the WBE.

(2) A warm anomaly was associated with the counterflow.

(3) Immediately downstream from the crest of the surface temperature wave pattern, the data indicated subsurface shoreward motions. A tongue of high-salinity water extends shoreward from the high-salinity core of the Gulf Stream on the downstream side of the WBE, suggesting transport by the eddy.

When the WBE moved north of 34° N where the bottom topography is no longer affected by the Blake Plateau and the shelf slope is steep, the characteristics of the WBE changed. Between 34° and 36° N the dimensions of the WBE decreased. The average wavelength was 115 km and the height was 34 km. However, the average wave speed (31 km/day^{-1}) increased. The downstream increase in wave speed may only be apparent because the waves occasionally stall in their formative stages near the bump.

In the April case study, the WBE formed immediately downstream from the bump and moved to its position north of 34° N in about 7 days. The thermal manifestation of the WBE at the surface was a definite wave pattern. A cold lens within the WBE was displaced slightly downstream of the wave crest. The lens persisted for about 5 days in a region where the various oceanographic data indicated there were significant currents.

Overall, the differences in structure of WBE's found immediately downstream from the bump and those found further downstream but no further north than 36° N, suggest that WBE's decrease in intensity as they move downstream.

Ocean Circulation as Seen by Satellite-Tracked Drifting Buoys

Gerard J. McNally, *Scripps Institution of Oceanography, Experiment/User No. 42–2*

Drifting buoys were used to monitor the surface currents of the Subtropical Gyre of the North Pacific Ocean in an effort to assess the role that variations in this circulation play in ocean climate.

Drifting buoys were deployed in two regions of the Subtropical Gyre: the North Equatorial Currents between 10° and 20° N at approximately 150° W and the North Pacific California Current north of San Francisco some 400 km off the coast. The first deployments in the California Current and the North Pacific Current were made in January 1979. The drifters carried a battery pack providing a nominal life of 1 year. Deployment in the Equatorial Pacific was made at the end of 1978.

The drifting buoys used in this program were the same as the 70 drifters deployed in the North Pacific over the last 3 years. Each was equipped with a Handar buoy transmit terminal (BTT), Comant antenna, and powered by a mercury battery pack. In addition to position information, the buoys measured sea surface temperatures, battery voltage, and drogue system integrity.

Drift Buoy Component, NORPAX Anomaly Dynamics Study

Dr. A. D. Kirwan, Jr., *Texas A&M University, Experiment/User No. 27–1*

Drifting RAMS buoys were employed to map the large-scale circulation in the North Pacific Ocean for the anomaly dynamics study (ADS). The ADS, as part of NORPAX, was undertaken to understand and describe the large-scale response of the general circulation of the North Pacific to autumn and winter storm activity to predict the formation and evolution of large-scale thermal anomalies. The capability to predict these anomalies is thought to have important consequences for society in improving long-range climate prediction over the North American continent. These anomalies also have the potential to affect the performance of undersea surveillance systems because of their vast size and scale.

The ADS is predicated on the assumption that winter synoptic storms with scales of 2000 to 4000 km produce baroclinic changes in the mass field in the ocean on comparable scales. This field, once adjusted to the storms, tends to remain unchanged until the next sequence of storms. Moreover, in the absence of subsequent forcing, the storm-adjusted circulation pattern will tend to persist for long periods. The hypothesis to be tested by the ADS is stated as "the integrated effect of autumn and winter storms is the primary cause of the mid-latitude anomalies. The mechanism for their formation is a baroclinic adjustment of the mass field."

Three dynamic mechanisms were considered to be possibilities for the baroclinic response:

(1) The adjustment in the field of the mass is produced by the horizontal divergence of Ekman circulation and/or wind drift currents produced by the flux of kinetic energy from the storms into the ocean.

(2) The mass field is altered by the large-scale sensible and latent heat exchange between the ocean and the atmosphere.

(3) The distribution of mass is altered by vertical mixing across the main thermocline driven wind stirring and convective overturning.

The first-mentioned mechanism was selected as a preliminary choice because the necessary tools to conduct the measurements were available.

One of the critical parameters to be measured was the circulation induced by the storms. It was decided to employ RAMS near-surface drifting buoys because the anomaly locations were not known and because the anomalies can be advected away from their origin.

Most of the buoys deployed were the Scripps Institution of Oceanography spar buoys. (See figs. 30 and 31.) These employ a Handar BTT, Comant antenna, and a mercury battery pack designed for a 9-month to 1-year life. The rigid urethane sections are predrilled to accept the various units so that replacement can be made externally without disassembling the buoy. A thermistor probe sampled the ocean temperature at about 2 m depth, and drogue sensors were employed.

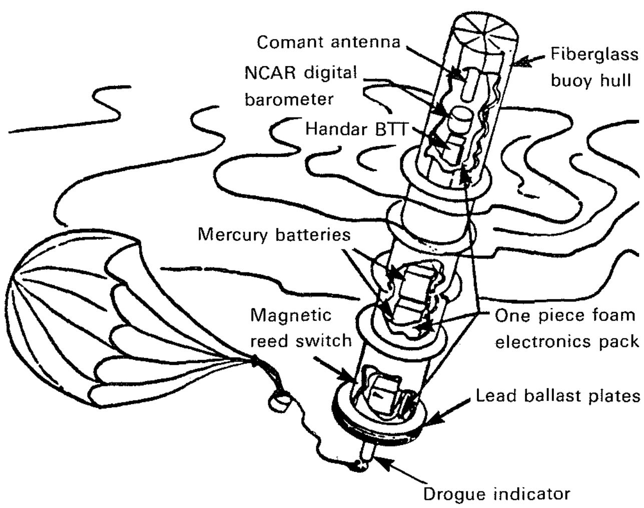


Figure 30.—NORPAX drifter system.

Eleven buoys were deployed in the fall of 1975. Four of these were an early NOAA Data Buoy Office PVC design, and apparently were not as rugged as the remaining buoys. As of May 21, 1976, 215 days after launch, buoy No. 1173 was still in operation. Figures 32 and 33 show the trajectory and velocity components derived from the trajectory. The mesoscale eddy structure is evident.

Sixteen more buoys left Hawaii in mid-june 1976, 15 of which were deployed in north/south lines in the North Pacific in an area bounded by 180° to 140° E and 30° to 50° N. By August 1976 only five of these were active. An additional 16 were launched in the same area later in the fall. During September 1976 these and other buoys had reported over 8000 sea surface temperatures through Nimbus 6, double the number processed by the U.S. Navy from ship reports that month. The temperature/time series for all the drifters showed the diurnal heating cycle as well as the long-term seasonal march from early summer through fall.

Preliminary data showed wavelike features along with a number of eddy mesoscale structures in the NEC similar to the preliminary findings by Hansen in the NECC.

From these and other data, two technical papers were presented at the American Geophysical Union meeting in San Francisco, December 6–9, 1977 (Berstein, McNally, White, and Kirwan: "Evidence of Oceanic Response to

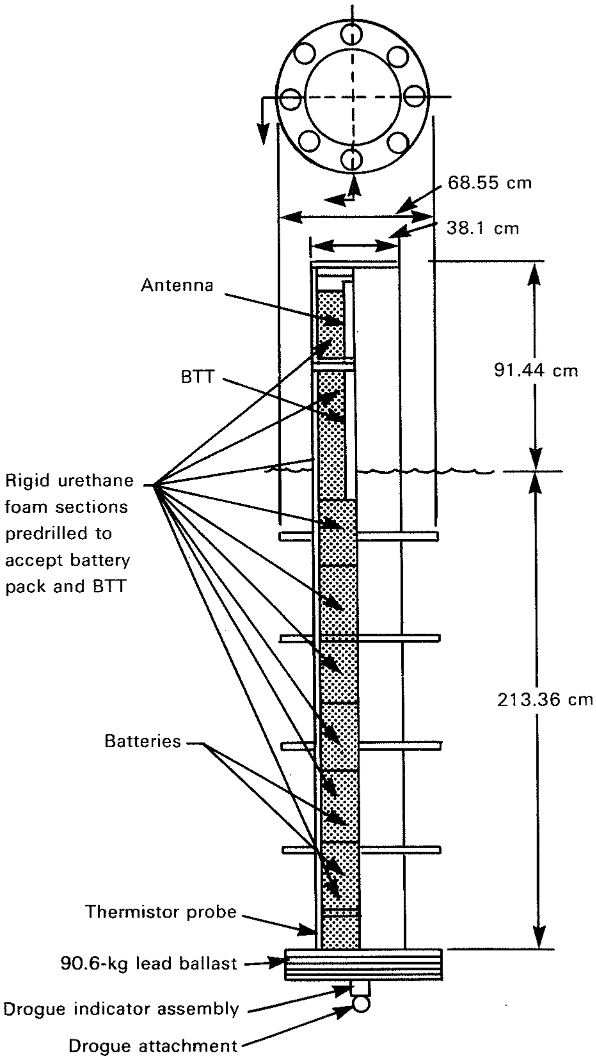


Figure 31.—Scripps Institution of Oceanography spar buoy **diagram.**

Bottom Topographic Forcing in the Mid-Latitude North Pacific"; and Kirwan, McNally, and Reyna: "The Circulation of the Eastern Pacific as Seen From Ship and Satellite.")

As a corollary to the drifter buoy program, a paper by **Kirwan and** Chang ("Effect of Sampling Rate and Random Position Error on Analysis of Drifter Data") was prepared for publication. It was found that at high sampling rates the position uncertainty can cause serious errors in estimating velocity and acceleration from unfiltered trajectory data. At low sampling rates the natural variability of the ocean currents may be the dominant source. It was shown that the optimum sampling rate for velocity is always less than that for acceleration and that the optimum sampling rate for calculating vorticity and divergence is the same as that for velocity. The RAMS appeared to be a reasonable compromise between the least effective position fixing system (over-the-horizon radar) and the most effective (local radar tracking).

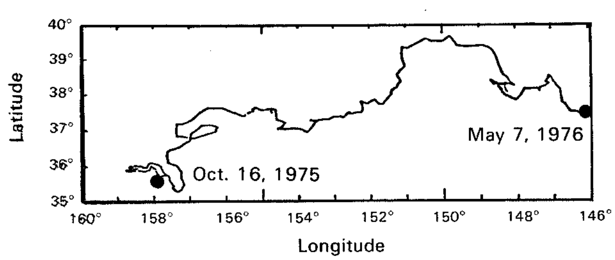


Figure 32.—**Trajectory** of Scripps Institution of Oceanography drifter 1173.

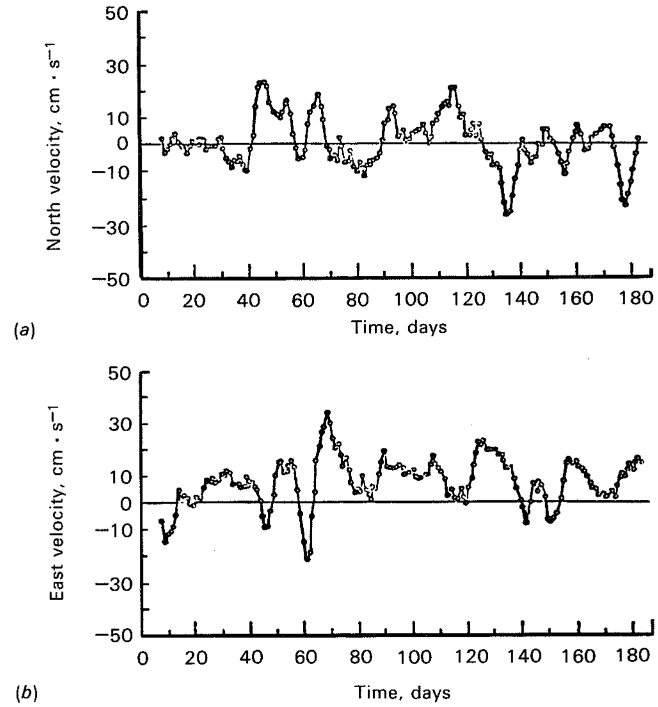


Figure 33.—Velocity of drifter 1173. (*a*) North velocity. (*b*) East velocity.

Scientific and engineering data are now being published on the trajectories of buoys and the variables measured. The trajectories, for example, indicate anomalies in the mesoscale eddy circulations of the ocean that were known to exist but were never measured as accurately or consistently as by the drifting-buoy satellite system.

It is expected that the next phase of the drifting buoy satellite investigations will use large numbers of buoys to yield accurate statistics. These buoys will be instrumented to measure surface temperature, heat content, and currents in the upper ocean; the surface temperature, pressure, and wind in the atmosphere; indirectly, the use of bulk formulas for turbulent fluxes; and the exchange of heat, momentum, and moisture between air and sea. They will be deployed in spatially coherent patterns embracing the energetic horizontal scales for both the ocean and atmosphere for extensive periods, and they will be located in regions where particularly important processes are thought to be occurring. The classes of phenomena to be addressed are elements of the general circulations of the oceans and atmosphere and their fluctuations and exchanges on short-term climatic time scales of several weeks to several years.

New England Outer Continental Shelf Physical Oceanography Program

Ronald A. Franklin, *Raytheon Co., Experiment/User No. 33–2*

Drogued buoys deployed on Georges Bank and tracked by satellite have provided comprehensive data on the seasonal current patterns. Evidence for a clockwise gyre circulation was obtained for the spring and summer seasons in agreement with the work of Bigelow (1927) and Bumpus (1975). Buoys, manufactured by Polar Research Corp., were fitted with 10-m-long canvas window shade drogues centered at a depth of 11 m. Positions accurate to a few kilometers were obtained approximately every second day by the Nimbus 6 satellite.

Lagrangian data collection was divided into four discrete experiments, each incorporating 4 to 6 buoys and lasting 8 to 10 weeks. Smoothed buoy tracks, as shown in figure 34, were prepared from these experiments.

Six buoys deployed in December 1978 followed clockwise trajectories to the southern flank of Georges Bank where they entered a current flowing southwestward, parallel to the isobaths. Three of the six buoys moved south out of this flow and became entrained in a Gulf Stream meander, while the others continued toward Cape Hatteras, where two were entrained by the Gulf Stream.

Because of the dominant southward motion observed over the Georges Bank in the first experiment, the March 1979 deployment pattern was biased to the north. The one buoy released on the southern flank failed prematurely. Contrary to expectations, the three buoys deployed along the northern side of Georges Bank moved northward into the Gulf of Maine. One buoy reached the southern flank and moved south, off the shelf and then to the east. The buoy deployed in the central part of the Georges Bank remained within the 30-fathom contour until picked up by a fisherman 8 weeks later.

Buoys deployed in May 1979 showed a well-developed clockwise gyre with return flow along the eastern side of Great South Channel and outflow on the western side. Subsequent bypassing of the channel by two buoys moving southwestward along the southern flank suggests that the return flow may be intermittent. The buoy that moved southward along the west side of the channel continued to track the 20-fathom contour around Nantucket Shoals, eventually passing within about 20 km of Martha's Vineyard.

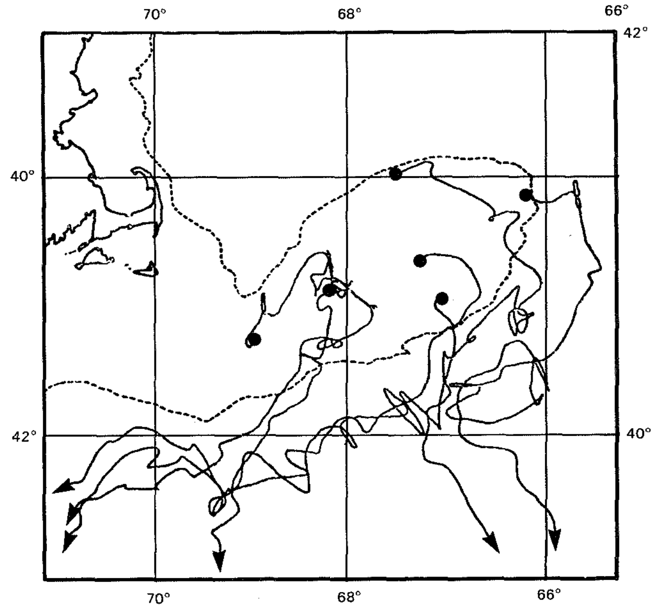


Figure 34.—Example of smoothed tracks from drogued buoys mid December 1978 to mid February 1979. The dashed line represents 50-fathom contour.

Results from late summer and early fall 1979 deployment showed a clockwise gyre dominating the circulation pattern. The gyre was closed on the eastern side of the Great South Channel, with several buoys making a complete circuit of the Georges Bank. Two buoys left the Georges Bank along the southern flank, one to the southeast and one to the southwest.

Long-term mean drift speeds for the buoys averaged 4 and 12 $km \cdot d^{-1}$ on the bank top. Speeds up to 30 $km \cdot d^{-1}$ observed along the northern flank on several occasions reflected the presence of a highly energetic current along the edge of the Georges Bank.

Residence times for buoys on the Georges Bank ranged from 10 days or less in winter to more than 10 weeks in summer and early fall.

Surface Currents in the Caribbean Sea

Dr. Donald V. Hansen, *National Oceanic and Atmospheric Administration, Experiment/User No. 7*

An experiment was conducted in the Caribbean Sea from October 1975 through June 1976 to map the distribution of surface currents. Lagrangian-drifter buoys tracked by satellite were deployed in the passages of the Lesser Antilles and within the Caribbean Sea. The buoy trajectories were considerably more complex than merely a westward drift, with several scales of meanders and eddies observed. The residence time in the Caribbean Sea for some of these buoys was more than 5 months.

Nineteen drifters were deployed in the eastern Caribbean Sea in two separate deployments. The first group of eight drifters was launched in the passages of the Lesser Antilles in October 1975. The second group of 11 drifters was launched in January and February 1976 in the Antillean passages and within the eastern Caribbean.

Position data were received from one buoy from October 1975 through June 1976, but the other buoys failed or ran aground prior to June. All the position data were edited in an automated computer routine and have a root mean square error of about 5 km. On the average, one to two positions were available per day after the editing.

Results from the data, figure 35, indicate that the flow in the Caribbean Sea is predominantly in the west at speeds of 50 to 75 cm/s. The mean flow accelerates sig-

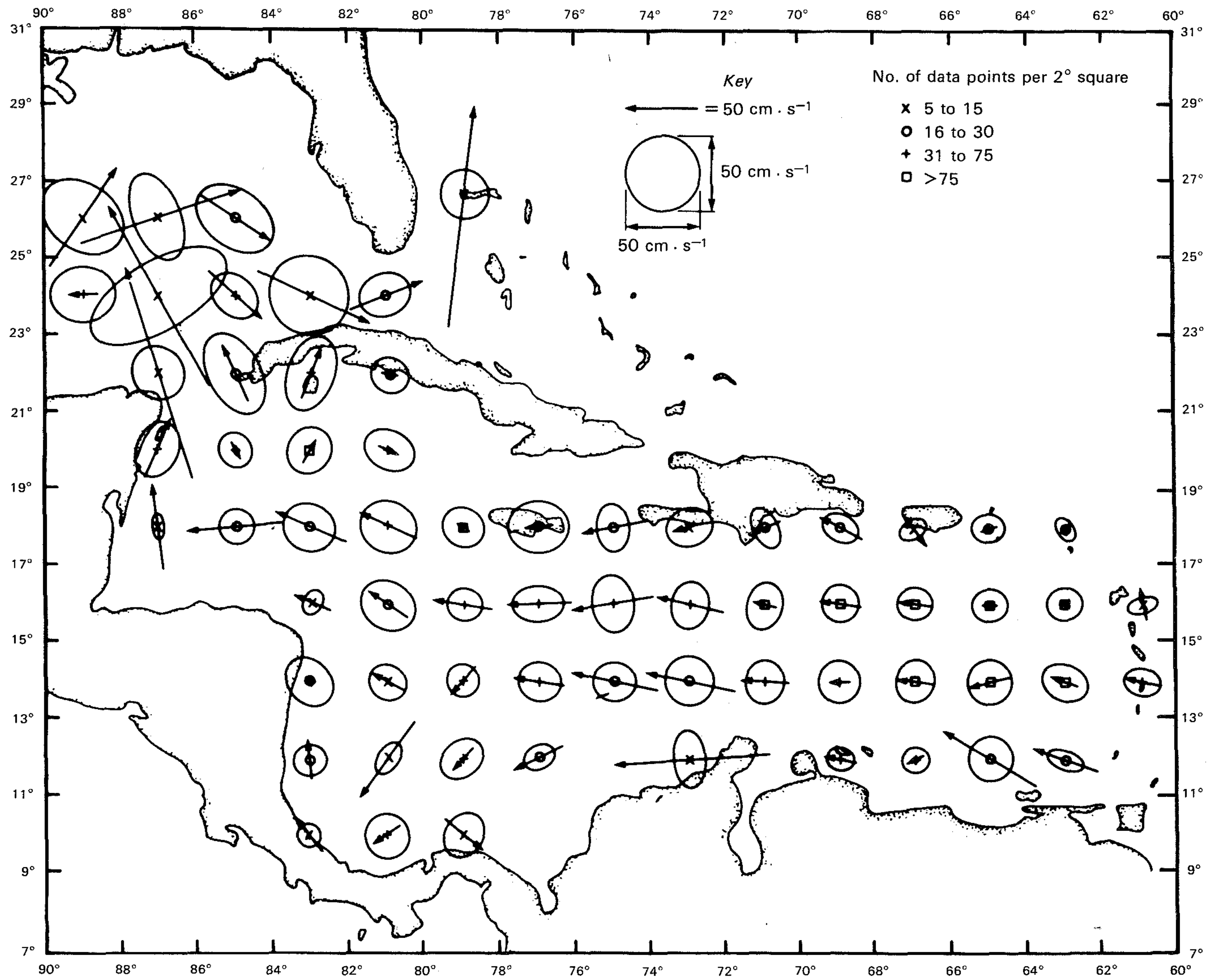


Figure 35.—Average currents in the Caribbean Sea and Gulf of Mexico for the period October 1975 to June 1976 as determined by averaging surface currents onto a 2° by 2° grid. The axes of the ellipses centered on the grid points represent the standard deviations of speed components normal to and along the mean flow.

nificantly in the Yucatan Straits first, and then again in the Straits of Florida. Downstream of both channels, speeds of over 150 cm/s are attained. Three gyres appear in the mean circulation patterns.

The individual buoy trajectories are also shown in figure 36. The trajectories are grouped by deployment area. The spatial character of the flow can be discerned from these trajectories.

Several observed features of the buoy trajectories suggest that the drifters are advected in the surface wind drift layer. For instance, the buoys deployed during January experienced greater drift speeds than those deployed in October. In addition, the northeast winds in the southeastern Caribbean occur over a region in which the surface drift of the buoys was predominantly to the southwest.

However, dynamic topographies collected previously in the eastern Caribbean indicate that the drifters may also drift with the geostrophic flow.

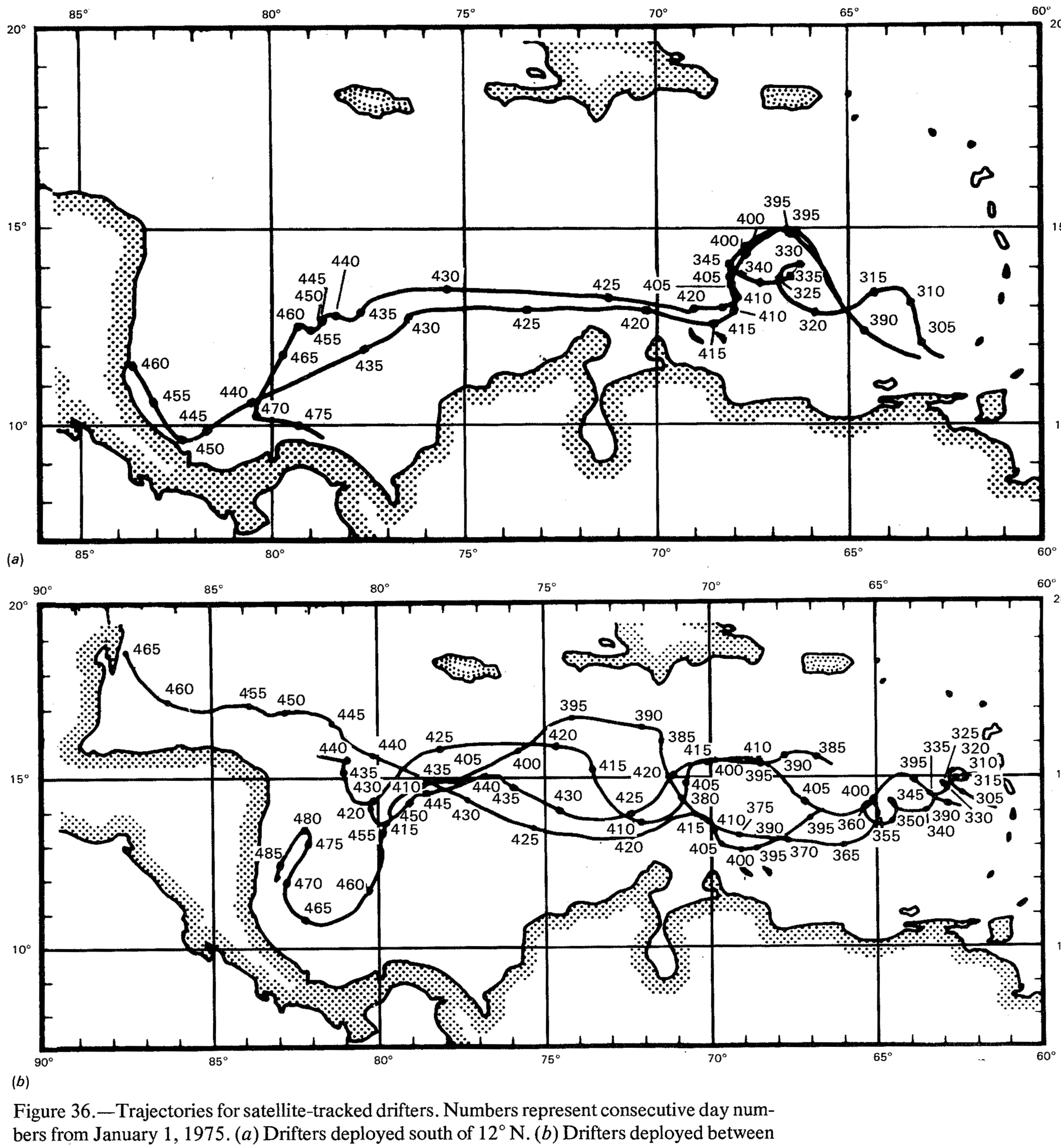
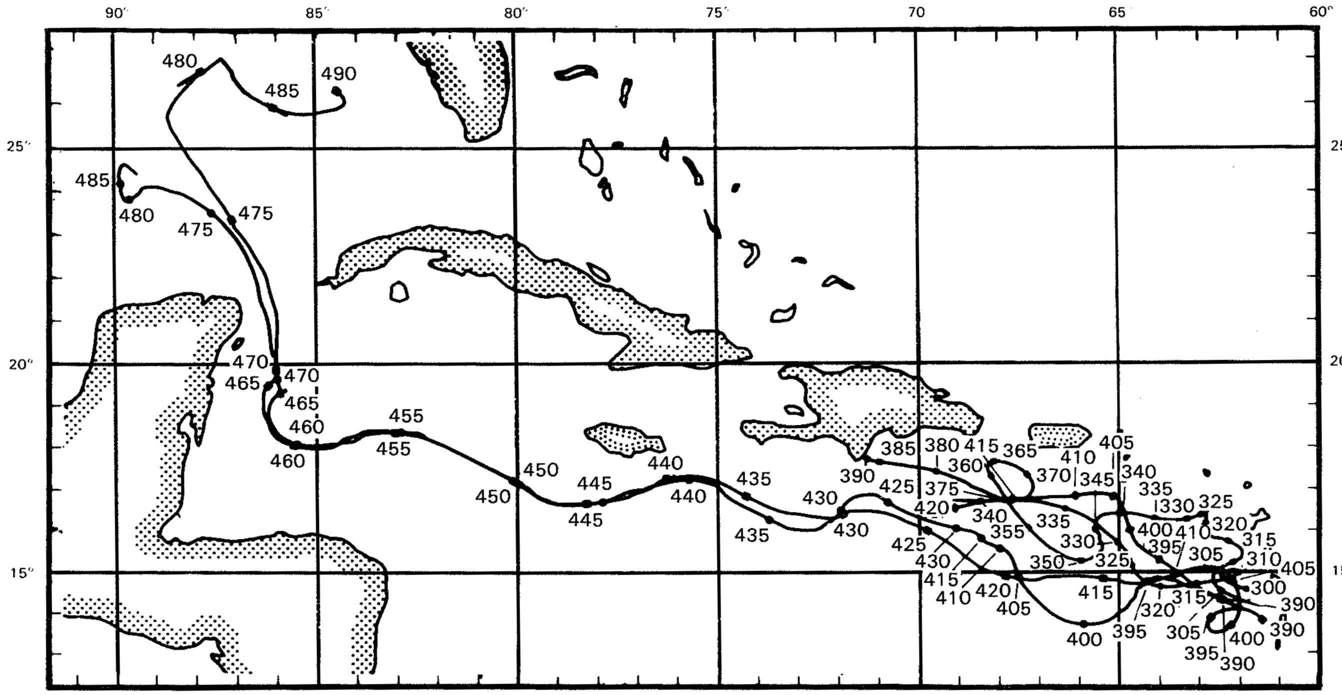
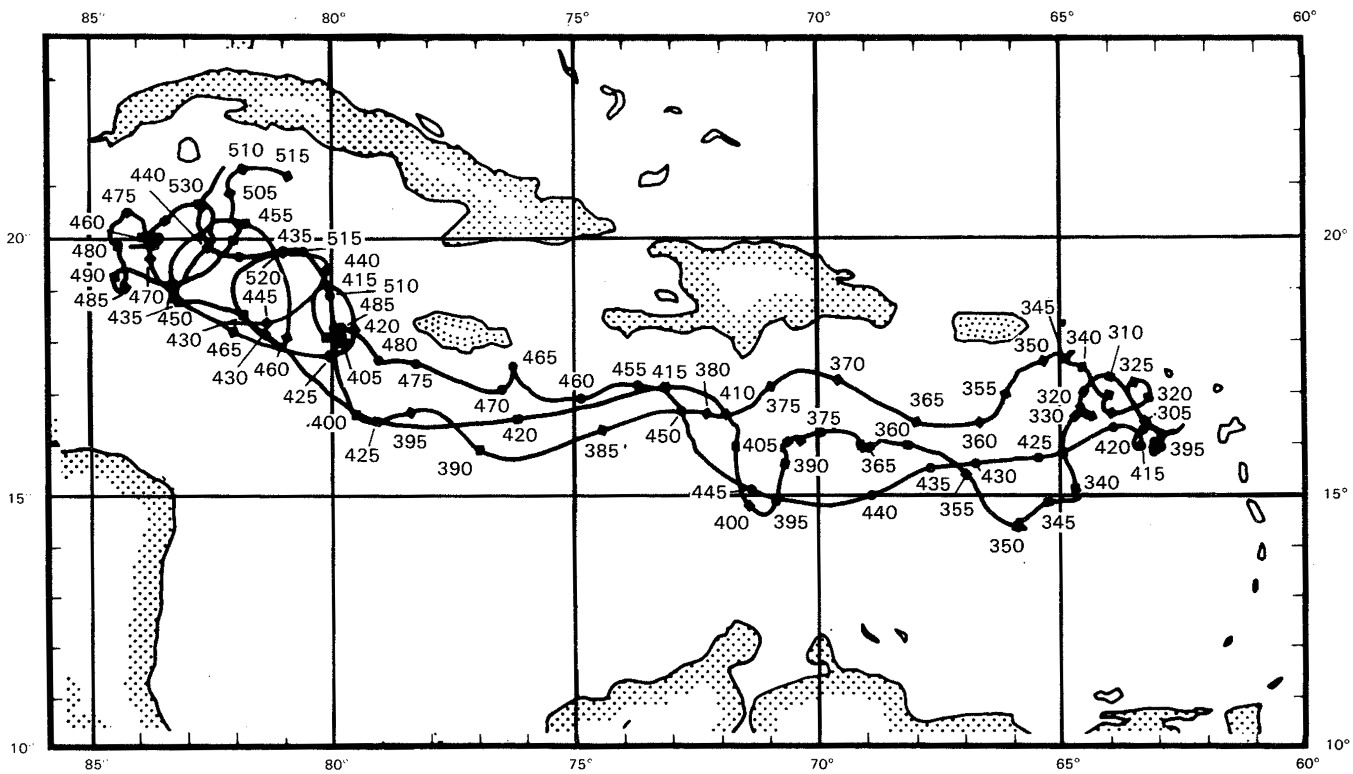


Figure 36.—Trajectories for satellite-tracked drifters. Numbers represent consecutive day numbers from January 1, 1975. (*a*) Drifters deployed south of 12° N. (*b*) Drifters deployed between 13° and 16° N.



(c)



(d)

Figure 36 (continued).—Trajectories for satellite-tracked drifters. Numbers represent consecutive day numbers from January 1, 1975. (*c*) Drifters deployed between 13° and 16° N. (*d*) Drifters deployed north of 16° N.

The trajectories show that the surface currents are more complex than those previously depicted. In particular, the frequent occurrence of meanders and eddies in the flow is responsible for longer residence time of surface water parcels in the Caribbean Sea than would be predicted from historical charts.

Drifter Buoy Experiment in the Eastern North Pacific

Ronald J. Lynn, *National Oceanic and Atmospheric Administration, Experiment/User No. 17–1*

Seven PRL drifter buoys were launched in a region about 32° N, 140° W, in June 1977. (See table 3.) A window-shade-style drogue was attached to each buoy by a 40-ft, ½-in. braided nylon tether. Sea surface temperature and a drogue presence indicator were encoded in the broadcast signal. The project was conducted in support of a study of the ocean frontal systems and the association of the seasonal migration of albacore with these fronts.

The subtropic frontal system was found to be very weakly developed when compared with observations from earlier years. The movements of the buoys while they retained their drogues were not particularly coherent with each other. Some traced cyclonic and anticyclonic paths. After losing their drogues, and especially during the winter months, the buoys moved in patterns related to the storm tracks.

Table 3.—*Summary of Results*

Drogue No.	Launch date	Date of drogue loss	Last transmission	Drogue retained, days	Total drogue life, days
230...............	June 19, 1977	Sept. 23, 1977	Mar. 3, 1978	96	257
114...............	June 21, 1977	July 1, 1977	Mar. 7, 1978	10	259
212...............	June 21, 1977	June 28, 1977	July 9, 1977	7	18
224...............	June 29, 1977	Sept. 26, 1977	Jan. 14, 1978	89	200
430...............	June 29, 1977	July 5, 1977	July 8, 1977	6	9
406...............	June 30, 1977	July 1, 1977	Dec. 24, 1977	1	177
122...............	June 30, 1977	Oct. 25, 1977	Feb. 8, 1978	117	223

Arctic and Ice Experiments

Satellite observations of Earth provide the opportunity to use remote sensor systems on buoys or similar platforms to obtain data from very remote regions. Several experiments were conducted using the Nimbus 6 RAMS in the polar regions. These experiments were concerned with arctic ice dynamics, iceberg movements, polar bear tracking, and environmental acoustics research. Remote sensors and transmitters capable of working with the RAMS were installed on these various objects for monitoring via Nimbus 6. Several of the experiments conducted provided data to support other experiment projects such as the French EOLE satellite, the arctic ice dynamics joint experiment (AIDJEX), the global weather experiment, and earlier wildlife tracking experiments. These experiments have shown that both positioning and data collection systems using the Nimbus 6 RAMS are possible. The results have opened up new possibilities for measurements and for data collection from remote and inaccessible areas.

Satellite Radio Tracking of Polar Bears

Jack W. Lentfer, *Alaska Department of Fish and Game, Experiment/User No. 15–1*
and
Dr. Douglas De Master, *Experiment/User No. 6–2*

Since the launching of the first orbiting satellites in the early 1960's, biologists and wildlife managers have been interested in using satellites to monitor individual animal behavior through satellite tracking. In tracking individual animal movements via satellite, wildlife concerns hoped to better understand animal life histories and use satellite information to help develop conservation and wildlife management programs.

In the early 1970's, the first attempt at tracking animals via satellite was made in Yellowstone National Park, using IRLS equipment on board NASA's Nimbus 3 satellite.

An 11-kg transmitter with solar cells and an IRLS receiver was attached to an elk's neck, but the experiment ended 28 days later.

In 1977, the U.S. Fish and Wildlife Service (U.S.FWS) contracted for the development of a polar bear transmitter to use with NASA's Nimbus 6 satellite, and the U.S.FWS biologists wanted to use the Nimbus 6 RAMS to track the movements of select polar bears—primarily pregnant females—for extensive periods of time to collect data on their den sites and production of young. Transmitters attached to the bears would send a location signal to the Nimbus 6 satellite that in turn would relay that signal to monitoring facilities at Goddard Space Flight Center, Greenbelt, Md. The U.S.FWS in Alaska would routinely receive computer printouts of the satellite data Goddard received.

Concern for the polar bear and his environment in the United States was aroused in the late 1960's with the discovery of large underground oil pockets in Alaska, and the subsequent start of construction of the Alaska pipeline in 1978.

Biologists knew from the earlier studies that many of the polar bear den sites were located in the same area as the Alaskan pipeline drilling.

Realizing that this increased human presence would affect the Arctic ecosystems—most immediately the polar bear— the U.S.FWS scientists began tracking polar bears in 1967, using ground and aircraft transmitters.

Because of the hostile climate and the ability of polar bears to remove early test collars, the RAMS transmitter package incorporated certain design techniques and components. (See fig. 37.) For example, the entire package weighed under 5 kg, making it smaller and lower in power than other Nimbus 6 transmitters. The design also included a loose-fitting, urethane neck collar design that would withstand the bear's abuse. The upper section of the collar contained the antenna, which would radiate a hemispherical pattern. A lexan box was used for the satellite communications electronics. The lower section of the collar (under the bear's neck) contained an 11-V lithium battery pack.

The collar design placed the antenna and electronics in the upper section and the battery pack in the lower section to balance the system and keep the antenna in an upward position. The package also included a secondary transmitter that operated independently of the satellite package as a backup and provided a continuous signal for ground and aircraft tracking. The collar was held in place on the bear's neck by a girth cable harness, which ran over the bear's shoulders and behind its front legs.

The scientists began their initial Nimbus 6 RAMS experiment using three mature female polar bears from Alaska that they numbered 1793, 1794, and 1795. These bears were fitted with transmitter collars during March and June 1977 and were then released at various points off the coast of Alaska.

Bear 1793, released 47 km north by northwest of Point Barrow, in March 1977, transmitted for 12 days, moving an airline distance of about 330 km to the north of her release site.

Bears 1794 and 1795 were both released in June of 1977. Bear 1794 was released 56 km north of Point Barrow and transmitted for 20 days, moving east against the direction of ice movement. Although the bear traveled against the westward flow of the ice—from an area of

Figure 37.—Polar bear with satellite-tracking collar.

broken and moving ice to an area of more stable ice—she was still able to advance 370 km east and 75 km from the shore of her release site.

Scientists received transmissions from bear 1795 for a total of about 390 days and over 1300 km after her release 50 km north of Point Barrow. At first she traveled east, but then she turned west-to-northwest, entering the Soviet sector around Wrangel Island as she followed the direction of the prevailing ice movement. Soviet biologists were notified about the bear and given frequency of the secondary transmitter. Although two Soviet planes searched for bear 1795, they were unable to find her or the collar.

The success of this initial experiment with satellite tracking led the scientists to expand their project in 1979. This new project was a cooperative effort between agencies of Norway, Denmark, Canada, and the United States.

In expanding the project, 11 bears, divided into three groups, were fitted with transmission collars and released at various points throughout Alaska, Canada, and Greenland. Four bears were released from Fram Ice Station, Greenland; four bears were released in the Beaufort Sea north of Barrow, Alaska; and three bears were released in Lancaster Sound, Canada.

In this segment of the research experiment, scientists hope to have better understanding of the degree of discreteness between different polar bear stocks. Scientists received good transmissions from 7 of the 11 bears fitted with transmitter collars. What became of the other four bears is unknown—their collars may have become detached or there may have been power failures.

Polar bear project scientists feel there is a continuous need for this type of satellite tracking of large mammals and that similar satellite tracking could be applied to birds and smaller mammals.

Iceberg Tracking in the Antarctic

Prof. P. Tchernia, *Museum d'histoire naturelle de Paris, Experiment/User No. 31*

CNES and NASA conducted an experiment to track drifting icebergs in the Antarctic and to study the Antarctic iceberg tracking previously conducted (1972–74) in conjunction with the French EOLE satellite.

The experiment goal was to place five radiobeacons on tabular icebergs off the Antarctica coast in a sector located at approximately 90° E. Earlier EOLE experimentation indicated previously unknown aspects of the east wind drift current in this region.

Five radiobeacon packages were built in France by the Laboratory of Dynamical Meteorology. These radiobeacons were assigned RAMS identification numbers 211, 256, 260, 422, and 474. With the cooperation of the Australian Government, two supply vessels serving Australian Antarctica shore stations in the desired region deployed the radiobeacons on random icebergs while enroute to the shore stations. It was recommended that the five radiobeacons be placed in the general region between 80° and 110° E latitude.

Beacon 422 was placed on a tabular iceberg at about 64°30′ S, 77°53′ E, on December 21, 1975. The signal from this beacon was never picked up by the Nimbus 6

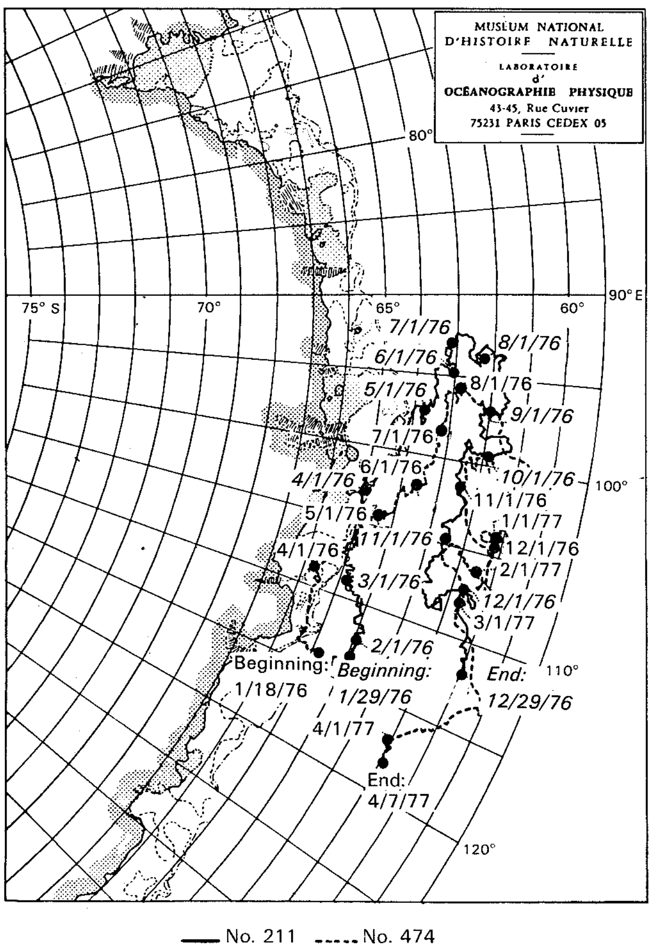


Figure 38.—Radio beacon 211 and 474 tracks via Nimbus 6 satellite.

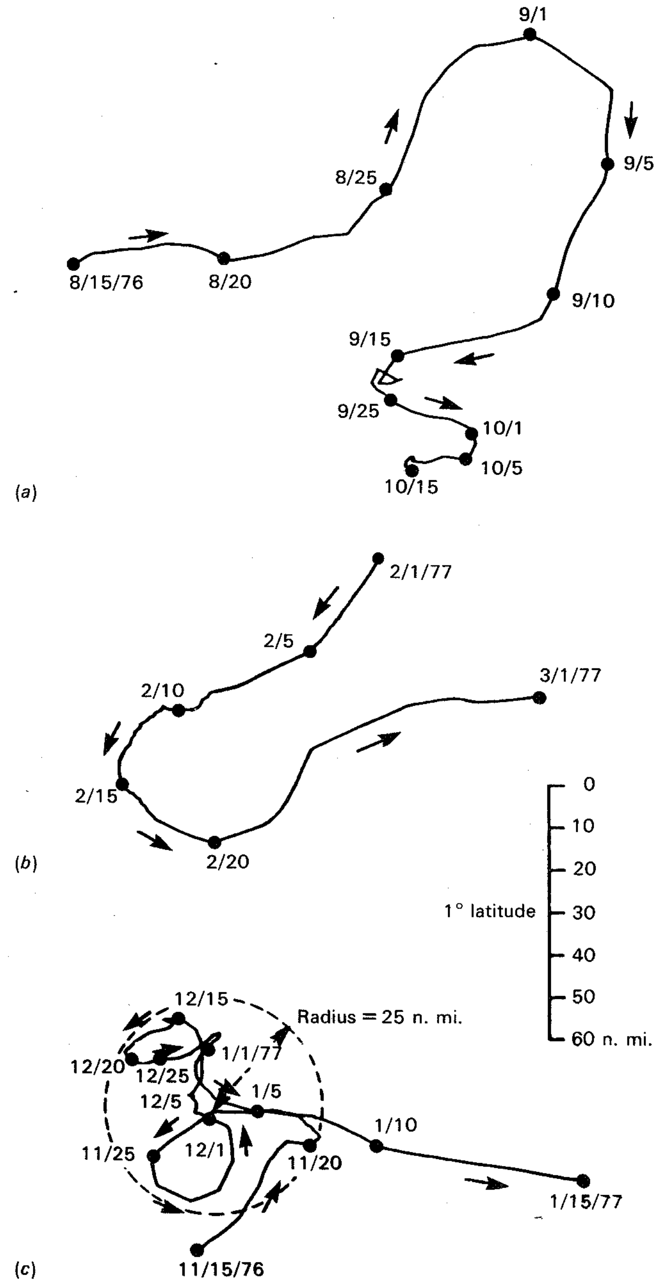


Figure 39.—Highlights of track of iceberg carrying radio beacon No. 0474. (*a*) August 15, 1976, to October 15, 1976. (*b*) February, 1977 to March 1, 1977. (*c*) November 15, 1976, to January 15, 1977.

due to the failure of the beacon. Beacon 260 was accidentally destroyed during helicopter operations while attempting to place the beacon on an iceberg. Beacon 256 was placed on a tabular iceberg at about 64°36′ S, 62°41′ E, on February 21, 1976. Successful tracking by Nimbus 6 was accomplished and the monitored iceberg commenced drifting west until it became permanently stranded at a position of 65°45′ S, 56°20′ E, on April 8, 1976. However, this beacon continued to operate and was detected over an operating period of nearly 3 years.

Beacon 211 was placed on a small tabular iceberg (approximately 400 m long by 220 m wide by 25 to 30 m above water) at about 63°48′ S, 113°03′ E in late January 1976. (See fig. 38.) Successful tracking lasted 335 days, during which the iceberg traversed and was tracked a total of 2300 n. mi.

Beacon 474 was placed on a tabular iceberg (approximately 1400 m long, 25 to 35 m above water) at about 64°42′ S, 114°0′ E, in January 1976. Successful tracking lasted 474 days, during which the iceberg traveled 2533 n. mi. (See figs. 38 and 39.)

The results of the Nimbus 6 RAMS satellite tracking of the Antarctic icebergs confirm and extend the results of the previous observations made by the EOLE satellite. It was found that it is possible via satellite to track radiobeacons mounted on remote icebergs on a daily basis. These icebergs were tracked for approximately 1 year over a range of 2000 n. mi. with an accuracy of 3 to 5 n. mi.

Five different trackings made between 1972 and 1973 in the region between 85° and 100° E at different times of the year (April to November) showed a U-turn movement, or recurvature, between 62° and 64° S linking the east-west juxtacontinental drift current that rules the Antarctic zonal circulation between about 62° and 38° S. These experiments and especially Nimbus 6 tracks 211 and 474 show that around 90° E, as in the Weddell Sea, there is a permanent interaction diversion connecting the two parallel and inverse currents.

Icebergs 211 and 474, after 1 year and more than a 2000-n.-mi.-drift were quite on the same longitude as in the beginning, but 3° or 4° to the north.

The results of these experiments lead scientists to assume that such interactions between the two drift currents must exist in Antarctic areas, especially off the Ross Sea.

Arctic Research in Environmental Acoustics

Beaumont M. Buck, *Polar Research Laboratory, Experiment/User No. 16*

The causative relationships between ice dynamics and underwater acoustic relative levels and associated correlations with meteorological, geophysical, and oceanographic conditions were the subject of an experiment sponsored by the Office of Naval Research under contract to PRL. The acoustics experiment was added to the planned arctic ice dynamics joint experiment (AIDJEX) project to measure simultaneously underwater acoustic noise levels, which are caused primarily by ice dynamics, with wind drag and ice movement so as to provide a better understanding of the causes and mechanisms of noise. For this experiment, a new buoy for unattended use in icebound seas called the synoptic random access measurement system (SYNRAMS) was developed by PRL using the Nimbus 6 satellite for relaying data and position information.

The AIDJEX plan called for an array of 8 to 10 arctic environmental buoys (AEB's) to be deployed on a 400-km circle around the main AIDJEX manned camp, Big Bear, in the Beaufort Sea. The AEB is a high capacity buoy monitored and commanded via high-frequency radio from a manned central control station (CCS). Three prototype AEB's funded by the NOAA Data Buoy Office were supplemented by an additional seven funded by the National Science Foundation, the major AIDJEX sponsoring activity. The AEB, however, was not suitable for use in the acoustic measurements program because its large high-frequency antenna is difficult to quiet down acoustically and, therefore, could contaminate underwater ambient noise measurements. The SYNRAMS was developed to surmount this problem and because there was a need for a position and barometric sensor backup for the relatively expensive AEB's. Moreover, there existed a need for the development of an economical, easy-to-install arctic data buoy for scientific uses outside of AIDJEX.

Eight AEB's and 10 SYNRAMS buoys were implanted in the ice during the spring of 1975 in the Beaufort Sea. (See fig. 40.)

Each SYNRAMS was housed in a 20.3-cm-diameter by 1.6-mm-wall aluminum tube 5.2 m long with a 25.4-cm diameter by 1.2-m polyethylene antenna enclosure. The tube was inserted as shown in figure 41 through a 23-cm hole drilled in the ice by a gasoline-powered auger. SYNRAMS could float as a spar buoy during the summer should it melt free.

The station was powered at 12 V by ten 1000-A-hr carbon/air cells designed for a 2-year life. Energy stored in a power capacitor bank aided in supplying power to the 1-W transmitter during the 1-s transmitter bursts.

The SYNRAMS sensor consisted of a hydrophone, a thermistor, and a barometer. The hydrophone, located 30 m below water surface level, was tethered to the bottom end of the aluminum tube by a length of chain. The hydrophone and its associated electronics measured ambient noise averaged over a 4-s interval in four ⅓-octave frequency bands from 3.2 to 1000 Hz. The acoustical dynamic range was 48 dB.

The thermistor air temperature sensor was mounted near the top of the assembly and was thermally isolated by a wooden block. It measured ambient air temperature over the $-40°$ to $4°$ C range in $3°$ C steps. The barometer measured the atmospheric pressure over the 950- to 1050-mb range in 0.392-mb steps.

The oscillator controlling the frequency of the radio transmissions and the barometer electronics were temperature sensitive. These were housed just below the water line to take advantage of the very stable temperature (near $0°$ C) at that point.

Data were collected from the sensors at the "standard synoptic weather" times (every 3 hr beginning at 0000Z) and stored in a solid-state memory, the new data supplementing the old. The data were transmitted once a minute in 1-s bursts of 64 bits each.

Although the cooperative effort with AIDJEX terminated at the end of 1976, two of the original SYNRAMS buoys, 0723 and 1003, continued to transmit data into 1977.

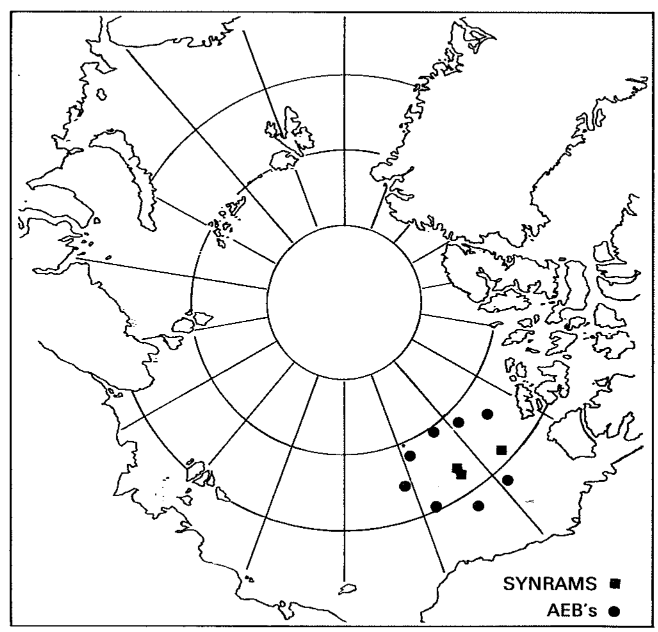


Figure 40.—Final data buoy installations at end of spring 1975.

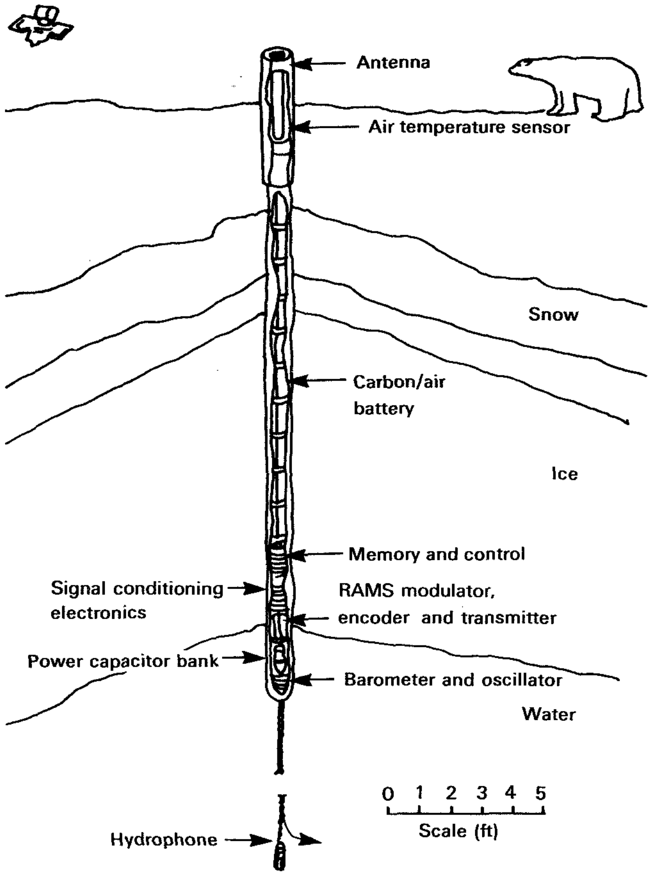


Figure 41.—SYNRAMS data buoy diagram.

SYNRAMS data buoys (0723 and 1003) hold the following "records":

(1) Longest life of an arctic data buoy
(2) Longest life of any drifting NIMBUS 6 data buoy
(3) Longest life of any NIMBUS 6 RAMS surface platform, land or sea, in an unattended or unvisited mode
(4) Longest arctic application of air depolarized batteries

The SYNRAMS data have enabled the development of a predictive model for ambient noise that has considerable promise for operational applications. It is based on an atmospheric pressure gradient, which is in turn easily derivable from isobaric weather maps.

The AIDJEX/acoustics RAMS program was an unqualified success. More and better acoustics ambient noise data were collected during the 1-year experiment than in the previous two decades. Never in the history of arctic environmental data logging has so much high-quality data been retrieved for such a low cost per data point to the end user. Prior to RAMS, acoustics ambient noise data were collected from manned ice camps—a very expensive and limited technique fraught with dangers to personnel. No data at all had ever been collected from ice manned stations in the summer, fall, or winter—only in spring when aircraft can land on ice. Even those data were largely contaminated by manmade noise. RAMS enabled continuous, uncontaminated measurements over the seasons at multiple geographic sites, an important consideration in acoustics.

Antarctic Sea Ice Data Buoys

Stephen F. Ackley, *U.S. Army, Experiment/User No. 20–2*

This experiment was conducted with the Nimbus 6 RAMS by the U.S. Army Cold Regions Research and Engineering Laboratory at Hanover, N.H., to determine the drift/strain relations in sea ice in the Weddell region and to obtain meteorological information (surface pressure and temperature) in the Weddell Sea.

Six buoys, both airdrop and ship-deployment types, were distributed on the pack ice of the Weddell Sea in the austral summer period. Their drift and movement relative to each other, when correlated with atmospheric driving, should provide a determination of the constitutive relationship governing the movement and deformation of sea ice in this region. The air droppable RAMS (ADRAMS) buoys transmitted data on location, pressure, and temperature to the Nimbus 6 satellite in a near-polar orbit.

The Antarctic Sea region is meteorologically interesting, but limited data are available because of the extensive ice cover and generally inaccessible conditions, especially during the winter period. The Antarctic Sea data coverage will coincide with the extensive data gathering efforts of the global weather experiment, being an important extension of this data set into high latitudes (south of 60° S).

The experiment began with airdrop deployment of buoys in December 1978; the second-phase ship deployment occurred in March 1979. The duration of the experiment was from mid-December 1978 to December 1979. The buoys were deployed initially between 60° and 40° W longitude, and 60° to 78° S latitude in the Weddell Sea. The drifting during the lifetme of the buoys distributed them between 60° W and the 0° meridian, and 55° and 78° S latitude by the end of the experiment. The data collected included surface air pressure, air temperature, and internal temperature of the buoys.

Two buoys ceased transmitting after 2 weeks, presumably crushed or overridden by moving ice; the other four buoys continued transmitting for approximately 4 months.

The drift of the southernmost buoy (buoy 1433; fig. 42), which remained active for the 4-month period, was dominated by a relatively steady northward component throughout the period, with cyclical movements associated with

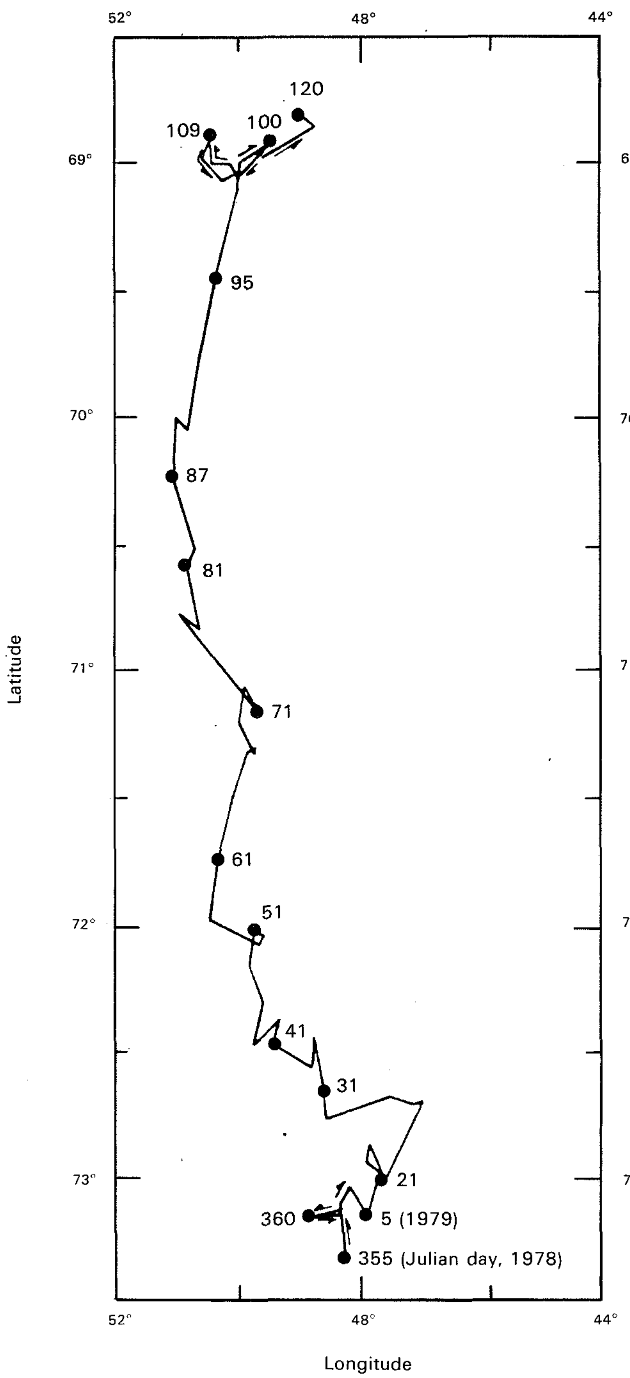


Figure 42.—Drift track of buoy 1433 from late December 1978 through April 1979.

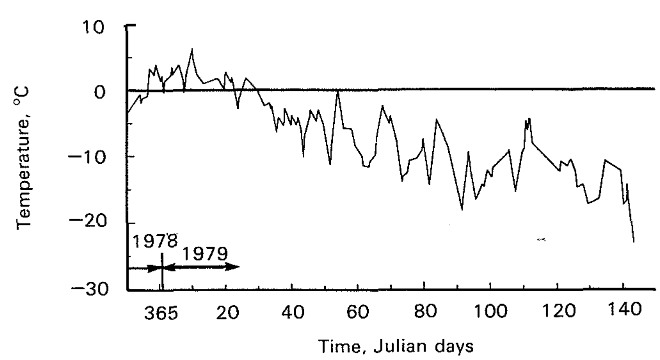


Figure 43.—Temperature record of buoy 1433 from late December 1978 through April 1979.

wind shifts from movements of occasional low-pressure systems across the region.

Following a relatively constant period of subfreezing temperatures during mid-February, the temperature record shows large temperature swings over 2- to 3-day periods (10° to 15° C) superimposed upon a mean temperature decline of 0.1° to 0.2° C per day. (See fig. 43.) The period of most rapid temperature fluctuations corresponds to the period of highest drift rate, perhaps indicating a series of cold air masses moved by strong southerly winds from the Antarctic continent. The deformational features of the buoy array indicate that the ice is undergoing almost continuous convergence during the summer/fall period, which is in agreement with the high ice ridging observed during the buoy deployment. Continuous ice convergence would limit the heating available through radiation absorption in open water and thin ice areas and, therefore, delay the disintegration of the pack by the lateral melting processes.

Ice Floe Tracking in the Arctic

William S. Dehn, *Sea Ice Consultants, Experiment/User No. 23–2*

This project deployed three PRL ADRAMS buoys on sea ice floes in the arctic. The overall objective of the experiment was to determine the forces producing sea conditions that might impact on offshore structures in a specific locale close to the north coast of Alaska. The buoys were equipped with barometric pressure and air temperature sensors.

Computation of sea conditions requires an accurate estimate of wind fields. The estimate used is based upon a surface pressure analysis (planned for the summer and fall of 1978) that requires accurate and frequent near real-time meteorological data, heretofore unavailable in this remote region.

Two buoys were dropped late in July 1978, and the third buoy in early August 1978. Daily data were gathered during August and early September with sporadic acquisition occurring thereafter until mid-January 1979 due to the curtailment of Nimbus activities. In early May 1979, sufficient data were received on two of the buoys to ascertain their positions; as of mid-June 1979, all three were still transmitting.

The buoy (position only) that had been located on floating ice station T–3 failed. This battery pack was replaced in February 1980 when T–3 was located at 73.6° N and 176.4° E. The buoy again failed early in July 1980. The last position received from NASA was on July 2, 1980, at 74.5° N and 167.2° E.

Fortunately, when the buoy failed, Sea Ice Consultants, by maintaining visual detection from satellite imagery, in conjunction with the positions provided by NASA, was able to provide reliable guidance to the search aircraft. A landing was made and the buoy reactivated.

T–3 provides a platform for scientific data collection in the Arctic Basin and has done so for the past three decades. In addition, it provides information relative to the drift characteristics of this type of ice (effect of wind and ocean stress). It remains a usable platform, though its current track may take it into a position to exit the Arctic Ocean. The Naval Arctic Research Laboratory maintained a watch on T–3 during this period of time in the hopes that the scientific community would again man this platform. This possibility still exists.

The results of the initial RAMS data gathering proved to be excellent. Thereafter, the ice floe position information was valuable not only to this project but to other experimenters as well.

Arctic Ice Dynamics Joint Experiment

Dr. Norbert Untersteiner, *University of Washington, Experimenter/User No. 6–1*

AIDJEX was conducted under the auspices of the National Science Foundation, the Office of Naval Research, the Canadian Polar Continental Shelf Project, NOAA, and NASA. The objective of the experiment was to obtain a better understanding of the interaction of sea ice with the environment by measuring the motion of sea ice, surface atmospheric pressure, air temperature, and the ocean currents beneath the sea ice in the Beaufort and Chukchi Seas and in the Bering Straits.

The experiment consisted of deploying eight buoys in a ring that provided a time series of position and pressure data. (See fig. 44.) To provide position data needed to interpret shore effects on the main array, buoys with about 100-km spacing were deployed along the coast of the Beaufort Sea. Later, a number of other buoys were air dropped onto the ice in the Beaufort and Chukchi Seas, and two additional buoys were dropped onto the tundra for long-term tests of the pressure and temperature sensors. Data were gathered over a 1-year period. These data consisted of barometric pressure, surface air temperature, ambient acoustic noise, geographical position, ice-floe orientation, and ocean current velocity at the 10- and 30-ft depth levels.

The experiment employed three types of data buoys that use the RAMS locating system. These were SYNRAMS, meteorological and oceanographic, and ADRAMS.

Eight of the 10 SYNRAMS buoys deployed in 1975 before the Nimbus 6 RAMS launch were among the first buoys acquired when RAMS was activated. These buoys employed the first synoptic sampling and memory equipment to relay data through a polar-orbiting satellite.

Better use of the RAMS data capacity was made by improving the RAMS position fix accuracy through identifying satellite alongtrack errors from data obtained from fixed RAMS platforms. The information on the position errors of the reference platform was used to adjust the moving platform position data, resulting in radial position errors of less than 2 km.

The barometric pressure sensors employed were of two types: a Hamilton standard vibrating steel transducer, which drifted less than 0.1 mb per year, and a Paroscientific vibrating quartz beam transducer in which laboratory tests showed drift rates of less than a millibar. These later appeared to have drifted 1 to 7 mb in the field, but the effect may have been due to the associated electronics.

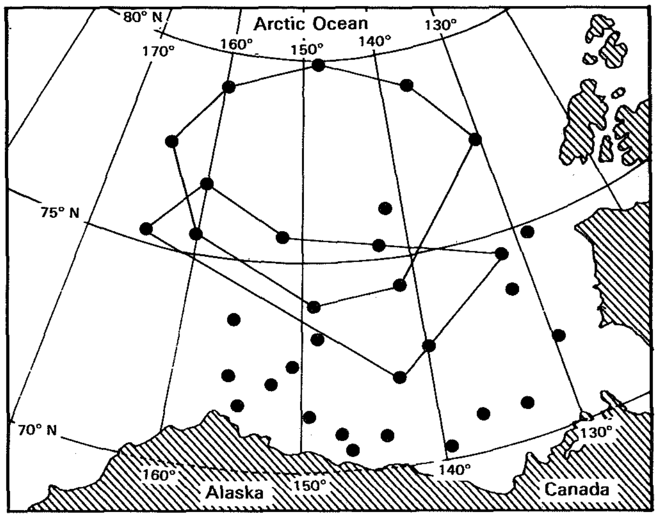


Figure 44.—Initial and final array of buoys for AIDJEX experiment, 1975–76.

The advent of the data collection and tracking Nimbus 6 RAMS enabled development of a relatively simple and reliable platform at low cost. As the platform cost per day decreases, the cost and reliability of the sensors becomes an important consideration and the cost of data processing becomes a major factor.

The RAMS buoy data were used to generate the barometric pressure field. From this field it is possible to predict the motion of sea ice using a mathematical model. The RAMS data were used further to test the validity of the model by comparing the predicted and the RAMS-measured motions.

Ice Drift Experiment in the Svalbard-Greenland Area

Torgny Vinje, *Norsk Polarinstitutt, Experiment/User No. 21*
and
Thor Haegh, *Royal Norwegian Council for Scientific and Industrial Research, Experiment/User No. 21*

This investigation was designed to obtain ice drift speeds in the Svalbard-Greenland area to help develop forecast rules for sea ice movements, to test numerical models for the ice circulation in the Arctic Basin, and to study the tidal influence upon the ice drift. This effort was supported by the Norsk Polarinstitutt and Continental Shelf Institute, Trondheim, Norway.

The development of the forecasting rules for the ice movements in these ice-packed seas is of great importance in connection with the shipping of coal from mines at Longvearbven and with the fishing and hunting activities that have a long tradition in this remote area. It is estimated that 80 to 90 percent of the drift ice that leaves the Arctic Basin passes through the Fram Strait between Spitsbergen and Greenland. Ice drift speed rates obtained in this area are of great interest in connection with the polar experiment of GARP inasmuch as these data may be used to estimate the outflow of ice from the Arctic Basin and thus serve as a control for the circulation models for the drift ice in the Arctic Ocean.

Buoys were developed by Chr. Michelsens Institutt. The design took into consideration the severe ice pressure expected to be encountered and was light enough to be easily handled and small enough to pass through a narrow aircraft door. The weight was about 55 kg, and overall height 0.8 m. The BTT was supplied by AEL. The transmitter, antenna, and lithium batteries were well insulated to avoid large temperature fluctuations. The design life was 3 months. (See fig. 45.)

Four buoys were constructed with RAMS transmitters for Nimbus 6 position location. Two of the buoys were equipped also with water temperature and battery voltage sensors.

Figure 45.—The buoy on the ice at 80.5° N and 7° E.

Buoy 0072 was equipped with both a bottom and an

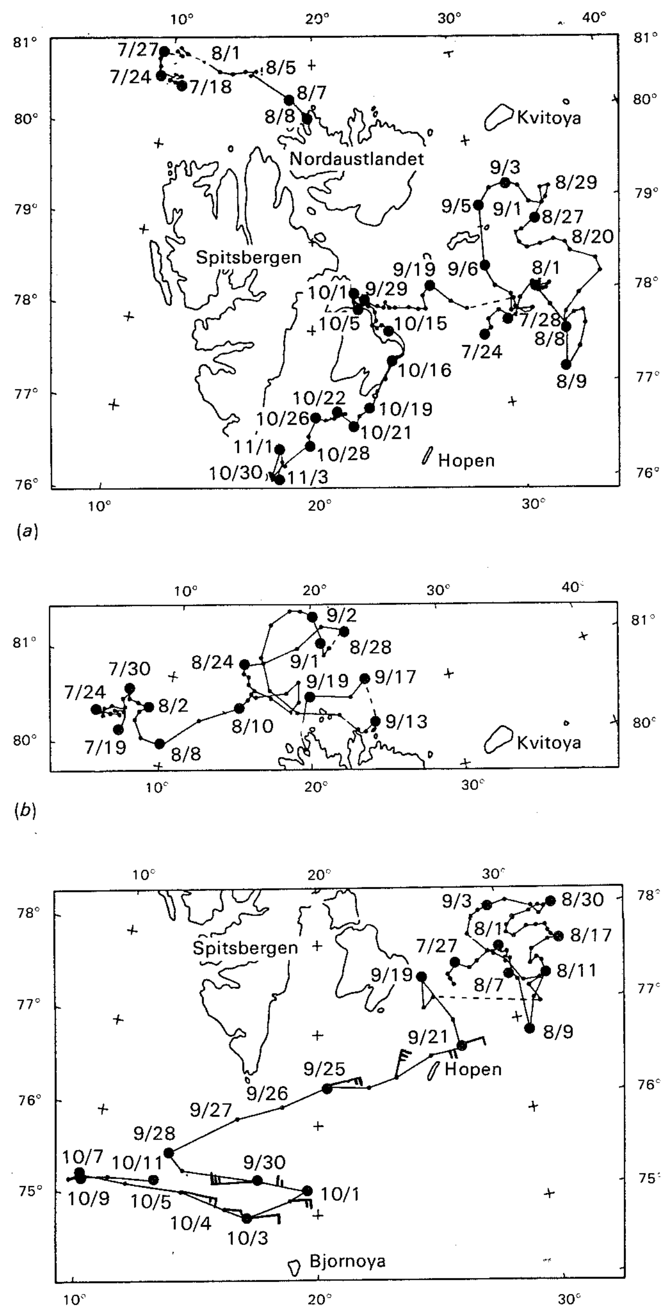


Figure 46.—Drift of the stations plotted by reading closest to noon. Numbers represent dates. (*a*) Station 0072. (*b*) Station 0044. (*c*) Station 0342 with observed wind data.

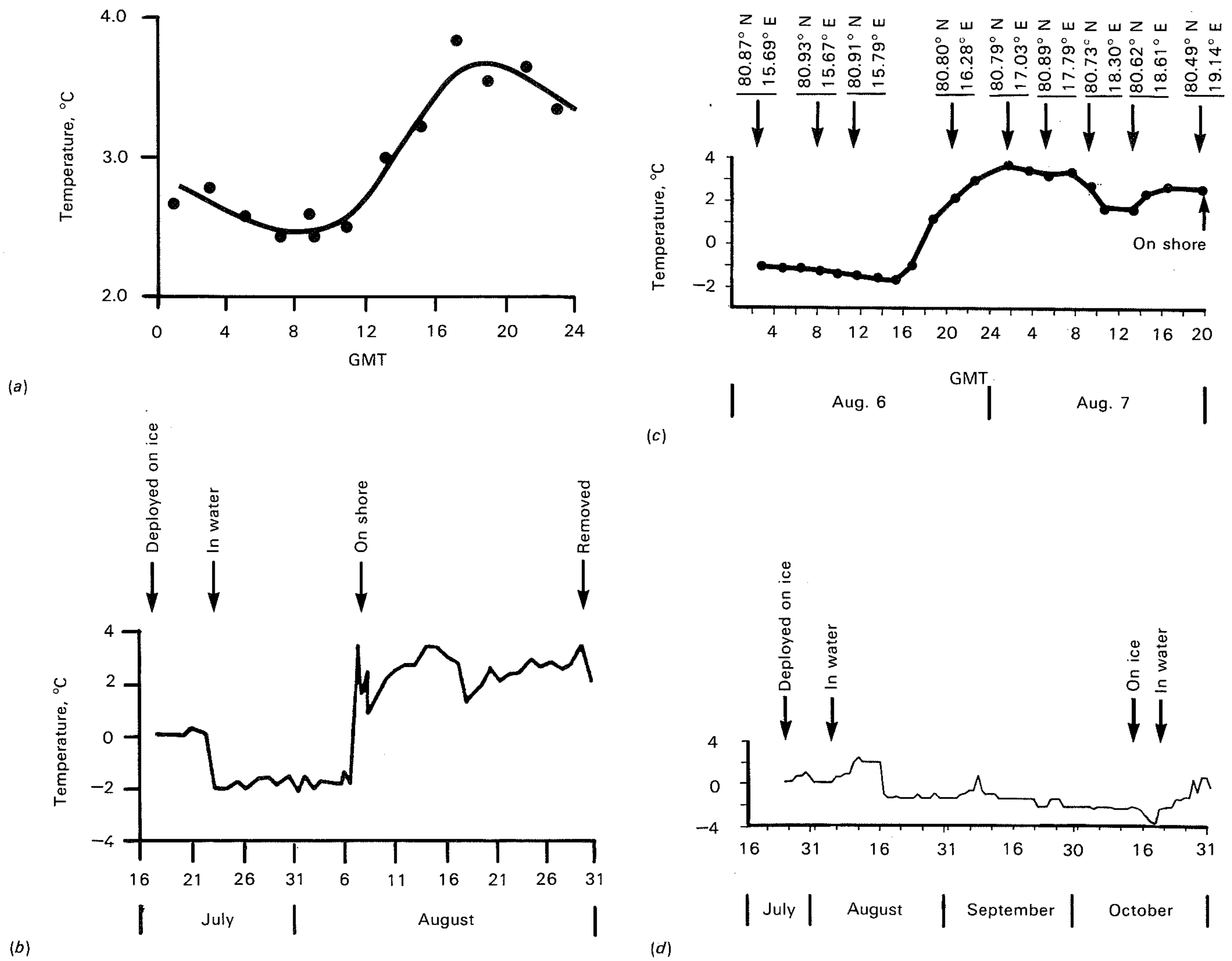


Figure 47.—Temperature observations at the bottom of the hull for stations 0072 and 0374. (*a*) Average daily temperature variation on shore, August 9 to 30. (*b*) Station 0072 temperature readings. (*c*) Detailed temperature readings on August 6 and 7 for station 0072. (*d*) Station 0374 temperature readings.

internal temperature sensor, and battery voltage monitor. It was deployed in July and was floating free of ice after a few days. (See fig. 46.) Sea temperature observations were made as it passed from polar water into the Atlantic Ocean.

Buoy 0044 was deployed in July at about 80.5° N and 7° E and was waterborne in less than a week. It reached as far north as 81.9° N, winding up in a deep fjord in September in a northerly gale. After the ice broke up in October, the buoy was transported northward, its transmission ceasing in December.

Buoy 0342 was deployed in late July, and it circulated in the eastern part of the Svalbard archipelago for more than a month in partially ice-covered waters. In the middle of September it was blown into open water and ceased operation after 81 days.

Buoy 0374 was equipped with a temperature sensor on the bottom that indicated whether the buoy was sitting on ice. The buoy was active for 102 days. (See fig. 47.)

Comparison with data from meteorological stations in the area indicated that the buoys were markedly more affected by wind when passing into ice-free areas.

Ice drift data turned out to be sparse and, while not useful for this particular experiment, were of interest both for drift conditions in this area and for future experiment planning. In the eastern part of the archipelago, buoys 0342 and 0374 made large circular counterclockwise movements in highly concentrated drift ice during August and September. It is believed that this circulation was mostly wind driven, and is in opposite rotation to sea current circulation in this area.

The RAMS position data were reliable and valuable for data collection in such remote and inaccessible areas. The position data accuracy averaged 1 km from true position with a maximum deviation on the order of 3 km, well within the 5-km upper position error limit requirements.

West Greenland Iceberg Drift and Ocean Current Investigations

Larry Brooks, *Chevron Oil Field Research Co., Experiment/User No. 41–1*

Another experiment using the Nimbus 6 RAMS was conducted to obtain iceberg drift and ocean current data in the Davis Strait, off the coast of Greenland. This experiment was designed to determine the feasibility of mathematically modeling iceberg drift, and to investigate drift patterns that would affect possible oil spills.

This effort was financed by the West Greenland Petroleum Concessionaires, which included several U.S. companies. The Concessionaires hold the West Greenland offshore concessions.

Initially, four buoys manufactured by PRL were deployed in the Davis Strait in the summer of 1976. Deployment was made in pairs, one tethered to an iceberg and the other free drifting with a current drogue. (See fig. 48.) Only RAMS position data were provided.

To tether the buoys to the icebergs, a 24-mm polypropylene rope about 750 m long was trailed from the ship and towed around the iceberg as seen in figure 49. The free end of the rope was retrieved, closing the loop around the iceberg, and approximately 200 m of the rope was hauled aboard the ship. The buoy was attached to the free end, and the other end spliced into the standing part. The result was a loose closed loop around the iceberg, with the buoy attached to the end of a 200-m tail.

The remaining two buoys were deployed to drift free with "window shade" drogues suspended from the bottom of the buoy. Depth was selected so that the buoy would be influenced primarily by the same sea currents as a typical iceberg (100-m draft).

Buoy 0577 was deployed at 64°25′ N, 54°24′ W, in June 1976, tethered to a tabular iceberg 20 m high, 130 m long, and estimated to displace 900 000 tons. The average drift until July 12 was roughly parallel to the 200-m depth

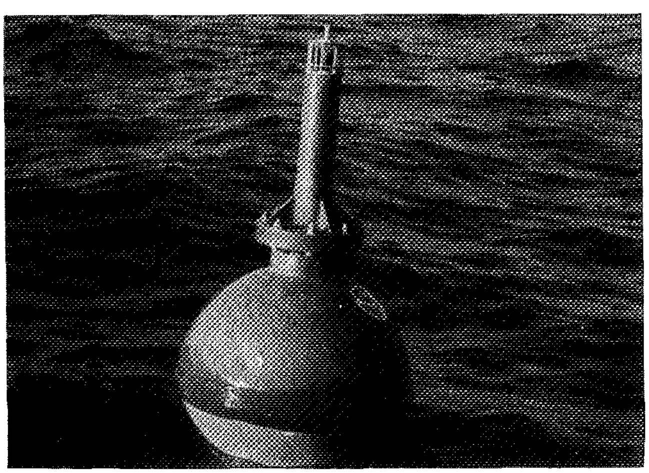


Figure 48.—Drift buoy and current drogue.

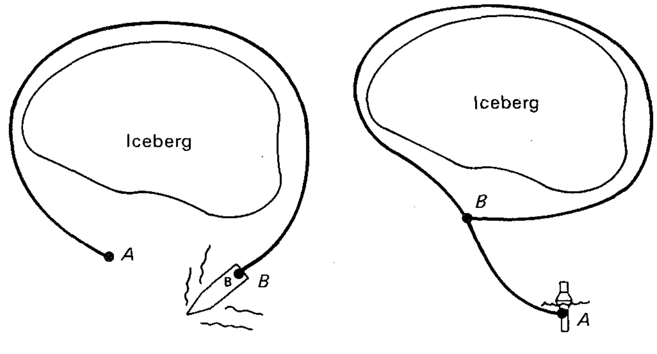


Figure 49.—Deployment of iceberg drift buoys.

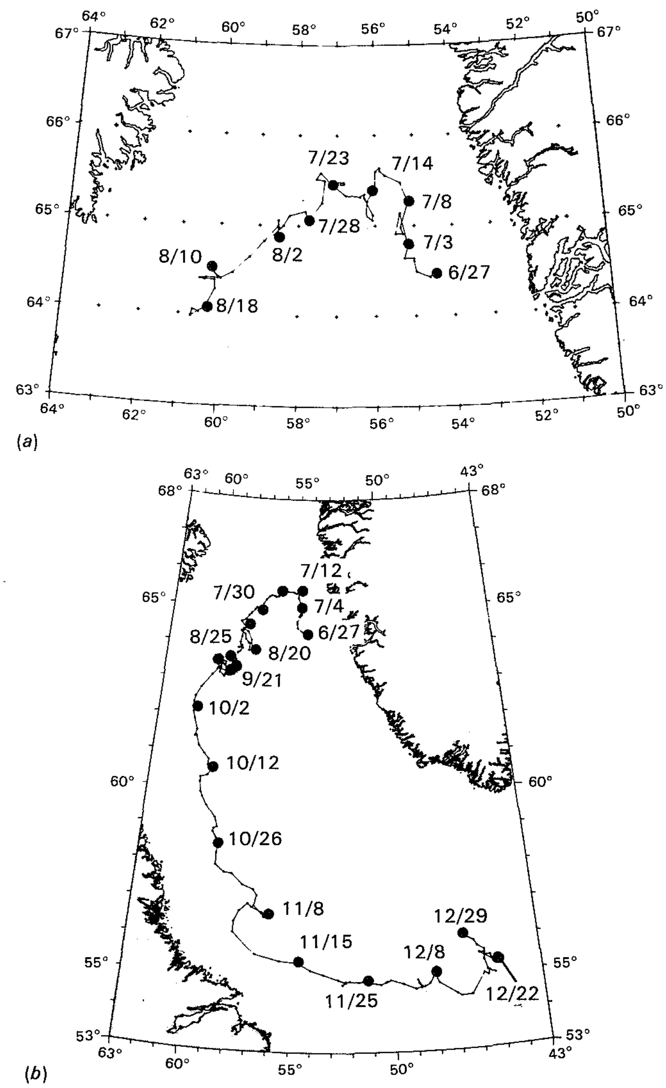


Figure 50.—Drift of two buoys deployed near each other on June 26, 1976. (*a*) Buoy 0577, tethered to iceberg; last data August 21, 1976. (*b*) Buoy 1137, with current drogue; last data December 29, 1976.

contour for 85 n. mi. After an erratic drift pattern up until July 24, the buoy drifted southwesterly until it stopped transmitting with no prior decay in signal quality in late August. (See fig. 50.) This buoy was recovered.

Buoy 1137 was deployed with a current drogue at the same time and location as 0577. The drogued buoy drifted in the same direction as the tethered buoy, but not as rapidly. It turned westerly after July 12, and from August 21, southward, until December 29 when it stopped transmitting. The buoy was recovered 2 years later east of Scotland in the North Sea by a fishing trawler, and has since been shipped to La Habra, Calif.

There was no significant difference in the drift of the two buoys deployed as a pair. However, the length of time the drogue and/or tether remained attached is unknown.

In general, the drift patterns of the buoys confirm the current patterns reported in oceanographic atlases for the Davis Strait; i.e., a north-flowing West Greenland Current that branches to the west and joins the south-flowing Labrador Current.

The lagrangian drift data are very unique and are believed to be the first such data for this area. When combined with the eulerian data collected by moored current meters, these data should enhance understanding of the complex Davis Strait sea current regime, particularly with respect to iceberg drift and oil spill migration.

Polar Pack Ice Tracking in the Beaufort Sea

J. C. O'Rourke, *Canadian Marine Drilling, Ltd., Experiment/User No. 36*

Canadian Marine Drilling Ltd. assembled an off-shore drilling system to drill for oil and gas in the Beaufort Sea in Canadian waters during the summer of 1976. The system consisted of two drill ships, supported by four ice-breaker supply vessels. The system operating plan included an oil spill contingency plan for use in the event of a major oil spill or blowout at one of Canmar's drilling locations. Even though the probability of a major oil spill blowout is extremely low, it is conceivable that during winter oil could find its way underneath the seasonal polar ice pack and be transported by it.

Canmar's first two drill sites were located approximately 50 miles north-northwest of Tuktoyaktuk in 100 and 200 ft of water. This experiment was developed to track the movement of polar pack ice in the Beaufort Sea using the Nimbus 6 RAMS over these two drilling locations. From the information obtained, it could be determined what the potential path would be if an oil blowout occurred at either of these two locations and lasted throughout the winter season. A second objective of tracking the movement of pack ice was to assess the frequency of its encounters with fixed structures in the area and to document pack ice features such as large multiyear pressure ridges and ice islands.

Ice Motion Measurement in the Canadian Arctic and Off-Shore Labrador

Dr. R. H. Goodman and Robert C. Atkins, *Innovative Ventures, Ltd., Experiment/User No. 40*

The purpose of the original experiment was to measure the ice motion off-shore Labrador during the spring of 1976. The objective of the measurements made was to develop a predictor model for ice floe movement needed by the petroleum industry for off-shore drilling. The experiment was expanded in 1977 to include the Canadian Arctic as well as off-shore Labrador. The experiment was designed to collect ice motion data using a combination of RAMS buoys, acoustic ranging and satellite navigation equipment, and the associated meteorological and oceanographic parameters. Ice thickness, ice pack strain, and ice strength measurements were taken to have a complete set of data that can be interpreted in terms of the AIDJEX model of ice motion. This program was funded by a consortium of oil companies working in these areas.

The ice motion was measured using the RAMS buoy at up to 10 sites in the Canadian Arctic. To improve the accuracy, a fixed-point transmitter was located in the center of the array, and motions were measured using translocation techniques. The RAMS buoy data were compared to an acoustic-ranging system with an ocean-bottom-mounted pinger. This acoustic system has an accuracy of 20 cm, but a limited-motion range of 1500 m. Simultaneous wind vector and ocean current vector measurements were taken at each site using the same recording equipment. The weather station measured wind speed and direction, barometric pressure, and atmospheric temperature. Sea currents were measured with a recording electromagnetic current meter. All data were recorded with a low-temperature data acquisition unit, together with the data retransmission facility of the RAMS system. RAMS buoys were deployed in the Sverdrup Basin (during the winter) and offshore Labrador.

Drift Ice Study in the East Greenland Current

Jan Dietrich and Dr. R. Zorn, *Danish Hydraulic Institute, Experiment/User No. 29*

This experiment was conducted for the Ministry of Greenland as part of the project "Environmental Studies Offshore East Greenland 1980."

The object of this experiment was to determine drift ice pattern and velocities of surface current and drift ice.

An automatic Nimbus 6 station was placed on an ice floe (ice island) of approximately 250 by 175 m, with a height of 6 m above the sea surface and a draft of about 20 m.

The preliminary presentation in figure 51 shows the track of the ice floe from the installation of the Nimbus 6 buoy on August 20, 1980, to January 8, 1981.

From August 20 to September 30, the drift speed was about 0.35 m/s in open pack ice. This relatively high speed, as compared with the expected current speed of 0.15 m/s, was the result of strong, northerly, 30- and 40-knot winds during this period. In the period from December 28 to January 8, 1981, the ice floe was trapped in the pack ice, with a drift velocity of about 0.09 m/s.

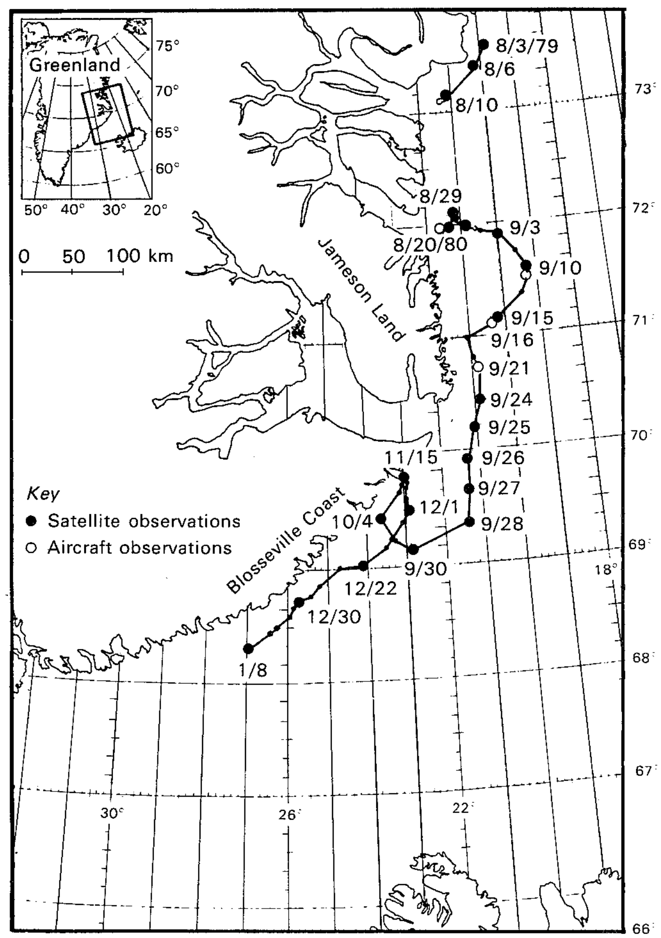


Figure 51.—Drift of automatic Nimbus 6 stations placed on ice floes off East Greenland, August 1979 and August 1980 to January 1981.

Marine Life Tracking Experiments

Satellite tracking of marine mammals, fish, and animals in the seas provides real-time data on movements, migration patterns, and behavior. Consequently, a number of investigations and experiments were designed and deployed using the Nimbus 6 satellite.

The four major experiments conducted with the Nimbus 6 RAMS included the porpoise tracking system experiment performed by the NOAA National Marine Fisheries Service, the Sea Turtle Movement and Migration experiment by the National Park Service, the larval herring patch study of the Bedford Institute of Oceanography and the NOAA National Marine Fisheries Service, and the basking shark tracking experiment conducted by the University of Aberdeen, United Kingdom.

Satellite-Linked Porpoise Tracking System

E. G. Woods and Dr. A. Kemmerer, *National Oceanic and Atmospheric Administration, Experiment/User No. 34*

Marine mammals, such as porpoises, have been the subject of considerable public concern because of their emotional appeal and involvement in commercial fisheries. In 1980, about 30 percent of the U.S. tuna catch was of tuna swimming in association with porpoises. The incidental porpoise mortality in the fishery has been reduced from about 400 000 in the early 1970's to about 20 000 in the early 1980's.

The Marine Mammal Protection Act of 1972 requires an evaluation of the impact of the fishery and maintenance of optimum levels of the porpoise populations. Assessment of the status of these porpoise populations is difficult because the fishery extends over more than 13 million km^2 of coastal and open ocean of the eastern tropical Pacific Ocean. Conventional tagging programs have provided useful information but cannot compare with the potential of a satellite tracking system:

(1) Satellite tracking would permit continuous tracking with real-time data on movements over extended time periods. Conventional marking provides only location, time, and biological data from only two points: the marking and recovery sites. Moreover, large research vessels are often unable to keep up with the faster porpoise and can alter the animals' behavior and movements.

(2) Resight or recovery or both of conventional tags is largely dependent on cooperation of commercial fishing fleets, while satellite tracking would be independent of fleets.

(3) The major cost of a conventional tagging program is the expense of chartering a tuna purse seiner to catch the porpoise and possibly another charter to resight the tagged porpoise. Vessel charters of tuna purse seiner vessels are about $10 000 to $15 000 per day, and a minimal tagging effort requires about 60 days. Because of these expenses, it is not possible to conduct a conventional tagging experiment of adequate dimensions to assess all porpoise stocks. Satellite tracking is infinitely more cost effective and would provide data on boundaries of the stocks as well as their movements and intermixings.

(4) Knowledge of the location of porpoises could be correlated with environmental factors for a better understanding of the animals' habitat. Incorporation of environmental and physiological sensors into the electronics worn by the dolphins would provide real-time data on their habitat while allowing them to serve as "mobile buoys" to gain information on the dynamics of the regional oceanography.

The objective of this experiment was to develop and demonstrate the feasibility of using a prototype satellite-linked tracking system to follow movements of wild dolphins. The experiment was conducted and funded by the NOAA National Marine Fisheries Service.

Development of a prototype tracking system commenced in the spring of 1975 using state-of-the-art techniques. The first transmitter fabricated for porpoise tracking was a modified version of one originally developed for use on NOAA National Data Buoy Office drifting buoys. Unfortunately, the off-the-shelf unit was unsuitable for application to a dolphin.

Efforts began to develop a small, lightweight transmitter pack that could be carried for several months by these sleek animals. Analysis of the porpoise's form and behavior was necessary to design a unit suitable to the animal while meeting the specifications of the satellite system.

After years of testing and modifying the design, a final Nimbus 6 prototype package was developed. The unit consists of two connected cylindrical aluminum tubes

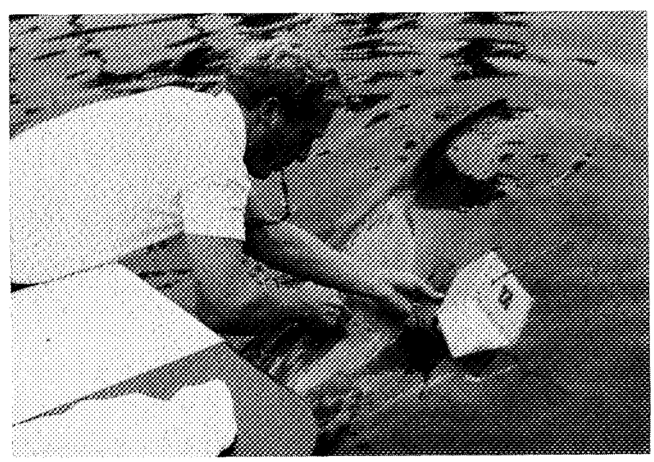


Figure 52.—Scientist attaching marine mammal transmitter to a porpoise.

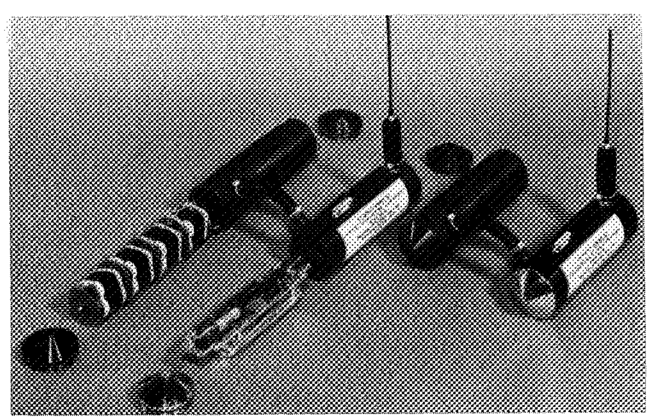


Figure 53.—Marine mammal transmitters.

with the electronics contained in one side and the batteries in the other. The two tubes are about equal in weight and measure 17.5 by 5 cm. The total package weighs only about 900 g and is placed on a saddle custom-fitted to the porpoise's dorsal fin. The unit is powered by 18 organic lithium cells and has a series of timers that conserve the battery power so the unit can transmit at predetermined times over several weeks. (See figs. 52 and 53.)

In June 1981, two wild Hawaiian spotted porpoises were instrumented with these prototypes and successfully tracked using the Nimbus 6 satellite for 2 and 7 days. The experiment was designed to last 2 weeks but, unfortunately, the antenna broke off one unit and the other unit appeared to have failed after 2 days.

The feasibility of using satellites to track wild dolphins has been demonstrated. Further reductions in the size of the pack are desirable so that the full potential of satellites for long-term studies of porpoises can be explored.

Georges Bank Larval Herring Patch Study and Drift Pattern Measurements off Southwestern Nova Scotia

Dr. Ronald W. Trites, *Bedford Institute of Oceanography, Experiment/User No. 41–2*

The larval herring patch experiment was part of a long-term study of herring stock in the Georges Bank/Gulf of Maine system. The major participants were the Bedford Institute, National Marine Fisheries Service of NOAA, and the Woods Hole Oceanographic Institution in Massachusetts. The experiment was designed to identify, measure, and track larval herring patches presumed to be carried by sea currents. The experiment was aimed at measuring relevant physical and biological parameters at the time the larvae are present. Included was the determination of the daily residual drift of the water mass in which the larvae are embedded, as well as the horizontal dispersion. Intensive, short-range tracking of drogues by ship was planned for a period from October 10 to November 10, 1978, as well as the installation of an array of moored current meters (6 sites, 24-m depth). Longer-term satellite tracking of buoys was planned for additional information on the survival of herring larvae that may have been carried by the currents into unfavorable areas.

Three drogued buoys constructed by Hermes Electrics, Ltd., Dartmouth, Nova Scotia, were obtained and equipped with Handar BTT's.

Unfortunately, no larvae appeared, so the buoys were not deployed. Subsequently, another experiment was planned to test the hypothesis that the surface-current pattern transports water directly from the Western Scotian Shelf into the Gulf of Maine during the autumn, winter, and spring months, but that during the summer months this flow pattern is interrupted by an onshore flow north and northeastward from Browns Bank. Further analysis of the physical oceanographic features of this area is important in terms of understanding drift patterns of lobster larvae and the larvae of other commercially important fishery stock. Additionally, it is generally considered that the flow over Browns Bank and past Cape Sable exerts a strong influence in the entire Gulf of Maine system. Thus, it is anticipated that the data gathered on this project will augment the intensive research projects currently being undertaken by the Bureau of Land Management and other U.S. agencies.

In April 1979, current meters were moored at six sites in the area. Surface drifters consisting of satellite-tracked buoys were also released during 1979.

Tracking of Basking Sharks

Dr. I. G. Priede, *University of Aberdeen, Experiment/User No. 19–2*

This experiment was conducted by the University of Aberdeen, United Kingdom, in support of the U.K. Natural Environment Research Council to track basking sharks (*Cetohinus maximus*). The objective of this experiment was to track these sharks with the Nimbus 6 RAMS satellite and from the tracking data determine the direction and speed of movement during the summer feeding activity and to determine the direction and timing of movement offshore in autumn.

Basking sharks feed on plankton near the surface of the sea during the summer. They swim with the mouth open, filtering food out of the water by means of fine gill rakers. An adult shark filters about 1500 tons of water per hour. Swimming requires energy, and it has been calculated that this fish can only survive if it can find and use the densest plankton patches to maintain a high energy intake.

The basking shark is the second biggest fish in the world, growing up to 10 m in length, but the problem of plankton feeding is generally applicable to a large range of smaller planktivorous pelagic fish of major economic importance. The basking shark grows very slowly, and its population is threatened by even low levels of commercial competition for its food.

These sharks are known throughout the northern North Atlantic but during summer feeding many are seen close inshore on the west coast of Scotland. It is at this time they are most accessible, swimming with the dorsal fin out of the water for much of the time (basking; see fig. 54). They are relatively placid fish cruising along at a steady speed of about 2 knots. Around November, when food becomes scarce, the fish probably move offshore into deep water and cease feeding, but little is known about where they go.

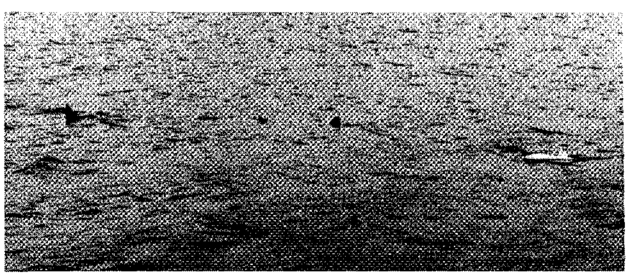


Figure 54.—Two basking sharks swimming near the surface with dorsal fins exposed. A typical summer sight on the west coast of Scotland, except that one shark is towing a Nimbus RAMS DCP in a yellow plastic pod.

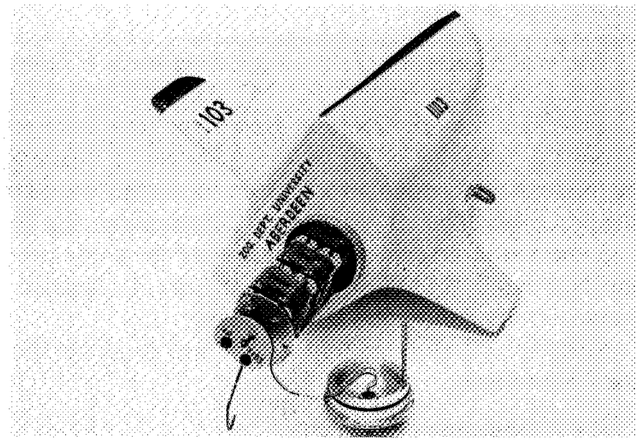


Figure 55.—Basking shark DCP package showing the insertion of the electronics into the inner pressure-proof casing.

For this experiment, four transmitters were deployed on sharks in August 1978 in the Kilbrannan Sound off Scotland. Each transmitter was enclosed in a buoyant pod about 1 m long which was towed behind the shark on a wire about 10 m long. (See fig. 55.) The wire was attached to the dorsal fin region of the shark by means of a barbed anchor injected using a hand harpoon.

After deployment, the transmitter assembly failed. As a result, no transmission was received by the RAMS instrument. Despite this failure, suitable transmitter configuration and attachment techniques were designed for use with basking sharks. These improved packages are being constructed for later tests.

Sea Turtle (Caretta caretta) *Migration and Movement in the South Atlantic Ocean*

Dr. D. L. Stoneburner, *National Park Service, Experiment/User No. 3*

The nesting activity of the Loggerhead turtle (*Caretta caretta*) has been studied for 14 consecutive years at Cumberland Island, Georgia. However, little is known about the behavior of these turtles shown in figure 56 beyond the brief period during which the female conducts the processes of beach ascent, nest construction, egg laying, and beach descent. The objective of the study using the Nimbus 6 RAMS was directed toward monitoring turtle activity before and after nesting.

More specifically, the experiment was to gather data for determining:

(1) Internesting movements
(2) Alongshore migrations
(3) Longer migrations that may occur during the hypothesized 2-year nesting cycle that is becoming apparent in the Cumberland Island turtle population

This experiment was conducted by the U.S. Department of the Interior, National Park Service, in Atlanta, Ga.

For this experiment, transmitters were attached to female turtles. The experiment was limited to female turtles because the male turtle does not present himself on the beach. The transmitter packages were attached to female turtles at Cumberland Island National Seashore, Ga., Atlantic Ocean.

The transmitter package is flat and curved to fit the shape of the shell and weighs approximately 3 lb. The package is embedded in inert polycarbonate and attached to the leading edge of the shell with splash-zone epoxy (nontoxic) cement. This configuration does not inhibit the movement of the animal and is more natural than buoys or balloons. There are no holes drilled nor any modification to the shell. This method of attachment includes a mechanical-biological, self-release mechanism, so that when the turtle grows, the epoxy bond attaching the package will fracture and the package will drop off. Growth is slow enough in the adults to assure secure attachment during the experiment.

The data collected with the sensors consisted of location, sea temperature, and turtle depth. All data, except location, were stored and dumped upon transmission. Because the turtle has a respiratory cycle of 25 min, the turtle came to the surface every 25 min to transmit data to the Nimbus RAMS.

The National Marine Fisheries Service and the U.S. Fish and Wildlife Service conducted a similar project using a 96-kg female loggerhead turtle named "Dianne." The purpose was to track with satellites large marine animals such as sea turtles.

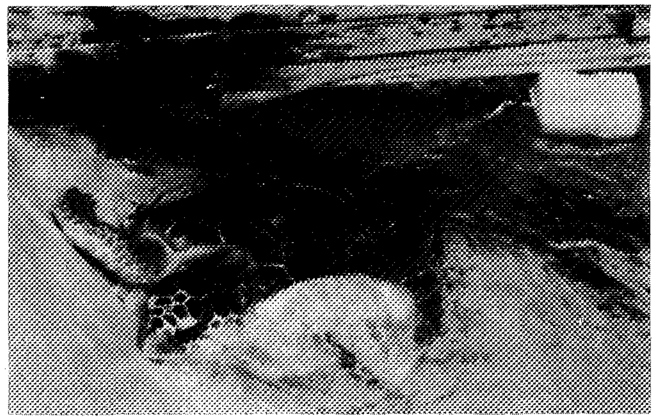


Figure 56.—Loggerhead turtle.

Dianne was outfitted with a specially designed satellite transmitter package that operated through a Nimbus satellite and relayed data to GSFC. Computer computations were made to locate the turtle, with accuracies approaching 2 km. It was designed to operate for 1 year, operating every 4 days for 8 hr duration.

The transmitter module was sealed in a 15.24-cm-diameter cylindrical plastic float about 25.4 cm long. Included in the float was a radio direction-finding beacon so that Dianne could be located by light aircraft or surface vessels equipped with portable receivers. The total weight of the transmitter float was about 3.2 kg. The float was attached to the rear of the turtle's shell by a 76.2-cm nylon line to allow the transmitter to surface when Dianne breathed. Previous experiments indicated that the transmitter float did not interfere with the normal behavior patterns of the turtle.

Dianne traveled southward around the mouth of the Mississippi River and westward along the Louisiana and Texas coasts to offshore Galveston, Tex. With the assistance of the U.S. Coast Guard in providing a helicopter, a mission was undertaken to photograph and observe the animal, evaluate her condition, and insure that the transmitter was still attached.

Dianne continued her migration southward to Corpus Christi, Tex., where she remained for several months. At this time, she began a northward migration in an apparent return trip. She continued northeast to a point offshore from Port Arthur, Tex., when there was an abrupt reversal. The transmitter was recovered from the beach and returned by vacationers who reported that the attachment lanyard had been cut and there was no indication of what might have happened to the turtle.

Navigation and Position Location Experiments

A number of experiments have been conducted in the past 5 years by NASA and other Government agencies to evaluate the feasibility of using low orbiting satellite and space technology for navigation, position location, and search and rescue operations for various vehicles such as small planes, boats, and similar moving objects.

The Nimbus 6 RAMS provided another opportunity to conduct experiments to determine the practicality of satellites for position determination, movement tracking and monitoring, and distress notification.

From 1975 to 1979, the Nimbus 6 RAMS monitored the movements of small craft in the ocean, transatlantic flights of balloons, expeditions in the Egyptian desert, and vehicles moving on interstate highways.

Each of these experiments was successful and further illustrated the potential offered by space technology for navigation and position location.

Distress Communication and Location System for Small Craft

James L. Baker, *Baker Development Corp., Experiment/User No. 5*

Small craft present an ever increasing problem in safety assurance in the U.S. coastal waters and offshore. In 1975 there were over 6 million registered recreational boats, and their numbers are increasing rapidly each year. Only about 5 percent have VHF radio or some alternative means for distress alerting. The annual average death toll is 1200 within 40 km of a U.S. coast. On the high seas, there is a lack of complete communication coverage, and each year more small crafts venture offshore.

Presently, distress signals may be detected via VHF marine radio within about 40 km of the coast, radio beacon, amateur radio, HF radio, and flares. Both low altitude and synchronous satellites have been proposed as an aid to search and rescue.

An experiment was developed for use with the Nimbus 6 RAMS to determine:

(1) The accuracy and practicality of using an 1100-km polar-orbiting satellite in conjunction with a doppler system for position determination in a search and rescue application for small craft at sea

(2) The feasibility of using a simple low-power encoding device for transmitting distress and safety-related messages

(3) The feasibility and practicality of using synchronous satellites in conjunction with low-power VHF communications from a small boat for satellite search and rescue

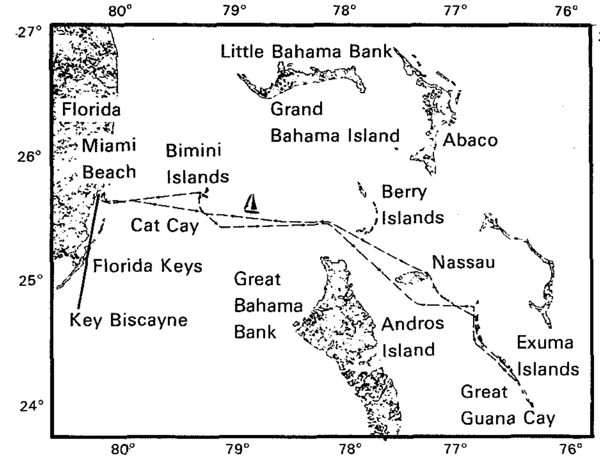


Figure 58.—Satellite-aided search and rescue at sea (voyage of the *Sirius*): accuracy of satellite-determined position of *Sirius*.

The experiment was conducted aboard the 32-ft sloop *Sirius* while cruising in the Bahamas area from December 18, 1976, to January 14, 1977. The experiment demonstrated message and position determination capability of low-powered, low-cost (i.e., $275 in production) equipment for use with the Nimbus 6 satellite for distress alerting.

Figure 57 shows the UHF equipment used for position determination and distress measurements along with the

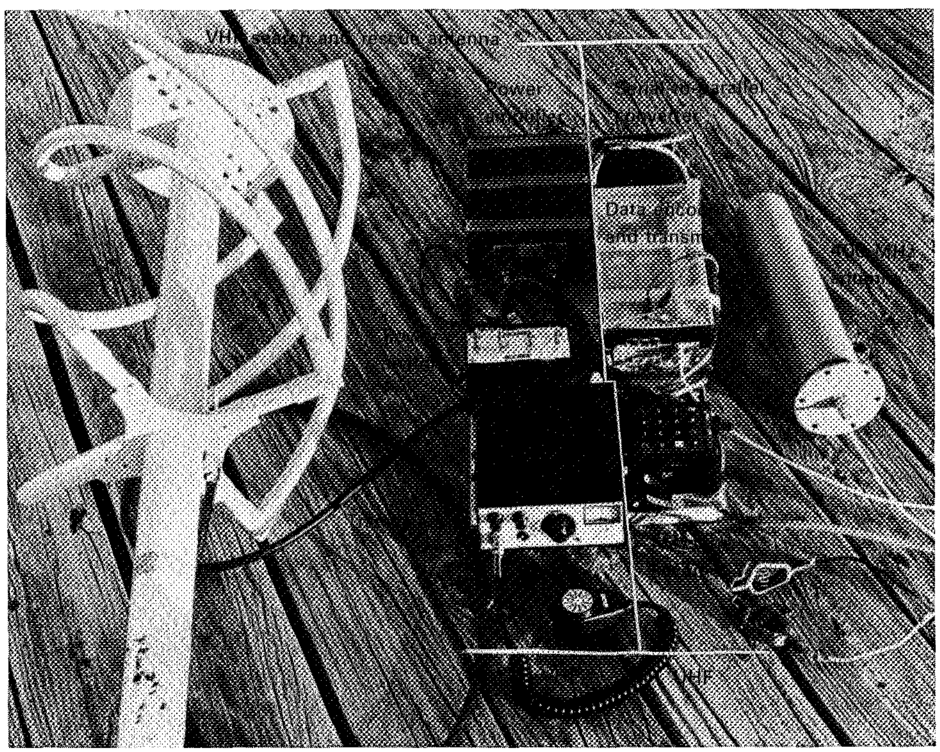


Figure 57.—UHF position determination and stress measurement and VHF voice coordination equipment.

VHF voice coordination equipment using the synchronous satellites ATS 1 and 3. The distress message keyer developed for NASA search and rescue experiments is shown in the lower right-hand side of the figure. This provided the manual encoding of simulated distress messages, position, and weather data.

Messages that could be entered at the keyboard and transmitted to Nimbus 6 were either simulated distress messages and emergency data or cruising condition data.

Because this activity was an experiment, no real distress messages were transmitted. Emergency procedures were worked out in detail in advance of the experiment. The four-digit codes were prepared and distributed to the appropriate ground station operators. Only one 4-digit code was intended for entry in the keyboard, depending on whether the situation was an experiment test code, a real emergency on board the *Sirius,* or a real emergency on board another vessel.

The *Sirius* departed Key Biscayne, Fla., on December 18, 1976, bound for the Exuma Islands. A number of daily excursions were made from the Exumas and the southernmost point reached was Staniel Bay. The return trip was commenced January 9, 1977, via Nassau and Bimini, arriving at Key Biscayne on January 14, 1977. (See fig. 58.) A variety of weather was encountered, including rough seas with 18- to 25-knot winds. Although the estimated time of satellite visibility was obtained in advance, the keyboard operator had to know the appropriate time of first visibility of Nimbus 6 during each pass to use the code effectively. Cruising condition data sequences were used exclusively so that rapid comparisons could be made between the known positions determined and those determined later by Nimbus 6 RAMS computer printouts.

Entering the data sequences into the keyboard proved to be time consuming and inconvenient because the Nimbus 6 orbit provided only three passes every 12 hr. These passes were spaced 107 minutes apart and occurred around local noon and midnight. The procedure required

Table 4.—*Accuracy of Satellite-Determined Position of Sirius*

Difference between satellite-derived and actual positions, km	Number of positions	Percent
0 to 1.0	52	45.6
1.1 to 2.0	34	29.8
2.1 to 3.0	14	12.3
3.1 to 4.0	2	1.8
4.1 and greater	12	10.5
Totals	114	100.0

about 40 min of operator time in making an entry every minute to insure transmission of the codes. This was necessary because of the uncertainty of the exact pass time and length of visibility. A radiofrequency monitor taped to the transmitting antenna emitted a 1-s audio beep marking the time of each transmission to Nimbus 6.

Table 4 shows the results of the analysis of the accuracy of the position of *Sirius* as determined by the Nimbus 6 RAMS. Seventy-five percent of the determinations were within 2 km of the true position of the vessel.

The experiment demonstrated the feasibility and practicality of using a low-orbit satellite system as an aid to search and rescue operations. The accuracy of the doppler-determined latitude and longitude of the transmitting vessel would reduce the radius to search within 2 n. mi. most of the time. The experiment also demonstrated the feasibility and high degree of reliability of transmitting messages by a simple code using a low-power, low-cost keyboard encoding device. These messages enhance the value of the position location by defining the specific type and extent of the emergency.

The use of synchronous satellite voice communications proved to be very efficient, effective, and reliable.

Use of RAMS in Following Trans-Atlantic Balloon Attempts

Nicholas Craddock, *Federal Aviation Administration, Experiment/User No. 17–2*

In this applications experiment the Nimbus 6 RAMS was used to provide timely position data on helium and/or hot air balloons and their crews as they flew from North America to Europe across the North Atlantic Ocean. This project was a cooperative effort between NASA and the Federal Aviation Administration.

The RAMS transmitter was on board the Double Eagle II balloon with Americans Anderson, Abruzzo, and Newman. The RAMS provided the position data that allowed the Double Eagle II ground support personnel, and the world, to follow Double Eagle II in the first successful balloon crossing of the North Atlantic, which terminated in its widely publicized landing in a field outside Paris in October 1978. (See fig. 59.)

In its first flight, the Double Eagle was swept northward to Iceland at speeds of 50 to 80 mph. The balloon was caught in a swirling snow storm off the southern tip of Greenland. The voice radios were washed out by rain for 17 hr. Using the RAMS location data, the control center in Massachusetts was able to direct a Navy patrol plane to the balloon location to rescue the balloonists as the balloon went down off Iceland.

In July 1978, a RAMS transmitter was carried aboard the balloon of British balloonists Cameron and Davey in their attempt to cross the Atlantic for the first time. Accurate locations to within 2 km were provided three or four times daily by the RAMS and passed by telephone to the balloon center at Brackwell, England, as the balloon progressed in 5 days from St. Johns, Newfoundland, to the final ditching 100 miles off the coast of Britanny, France.

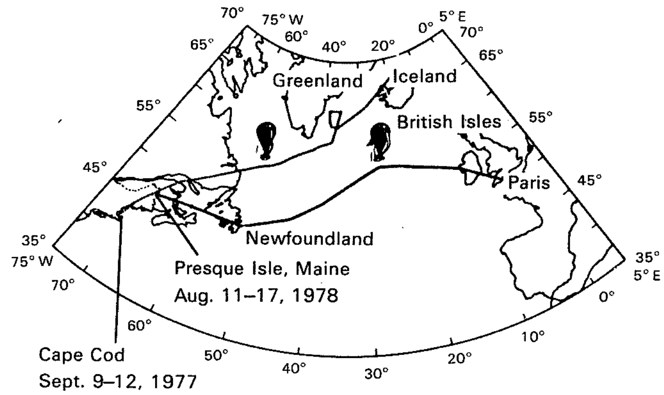


Figure 59.—Nimbus 6 track of Double Eagle balloon flights.

From a safety standpoint, the RAMS position data and on-board emergency transponders were major factors in the successful recovery of the Double Eagle I gondola and crew off of Iceland and British balloonists Davey and Cameron when they were forced to ditch their balloon. In October 1977, American balloonists Reinhard and Stephenson also had a RAMS transmitter on board during their abortive trans-Atlantic crossing attempt.

Dogsled Tracking

Dr. Lee Houchins, *Experiment/User No. 33–1*

The dogsled tracking experiment was requested by the Smithsonian Institution, which wished to compare Nimbus 6 RAMS-derived positions with Arctic explorer Naomi Uemura's dead reckoning and celestial navigation techniques used during his dogsled treks from Ellesmere Island to the North Pole and down the spine of Greenland in the spring and summer of 1978. The expedition itself was sponsored by the National Geographic Society, Japan's Mainichi newspaper and TV network, the Japanese magazine *Bungei Shunju,* and by numerous corporations and individual donors. The expedition also provided air pollution and weather data plus ice and snow samples for the Smithsonian, for Japan's National Institute for Polar Research, and the Water Research Institute of Nagoya University.

Navigation is a particularly difficult task in the polar region for several reasons. Wide expanses of indistinguishable ice-covered territory and the extreme environmental conditions must be dealt with. Furthermore, Earth's magnetic field is subject to wide variations, which makes navigation by compass useless.

Uemura left Cape Columbia, Ellesmere Island, in Canada's Northwest Territories alone by dogsled March 5, 1978, and crossed some 500 miles of frozen Arctic Ocean, reaching the North Pole 55 days later on April 29. From there he was airlifted to northern Greenland to commence the second leg of the expedition, which began May 10, 1978. For days he traversed the nearly 10 000-ft-high Greenland ice plateau, a total of 1678 miles to Nassarssuaq on the southern tip. (See fig. 60.)

A Handar electronics transmit terminal was mounted on the dogsled. It was powered by lithium batteries capable of operation down to −50° F. Even so, Uemura carried the battery pack in an under-the-arm pouch to insure reliability. Fresh batteries were air-dropped along with provisions at regular intervals.

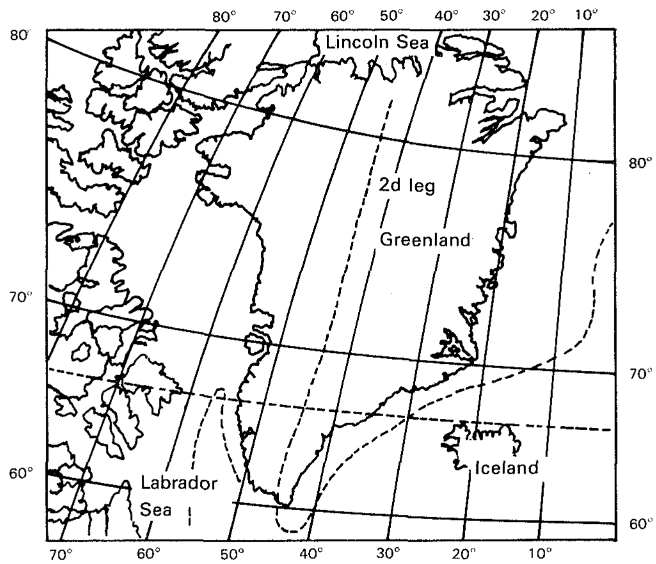


Figure 60.—Map of the Greenland and Iceland North Atlantic areas.

Four data channels were used for air temperature, barometric pressure, battery voltage, and emergency.

The emergency channel normally transmitted all zeros. A manual emergency switch was wired to apply full battery voltage. This was only used during testing and was never required in an actual emergency.

Vehicle Tracking and Location

Gerald Carp and John Sugrue, *Drug Enforcement Administration, Experiment/User No. 44*

The Drug Enforcement Administration (DEA) conducts a variety of operations throughout the world aimed at reducing the production, processing, and shipment of illegal narcotics into the United States. To meet this requirement, DEA constantly reviews current and advanced technology for application to DEA missions. With the cooperation of NASA, DEA earlier conducted a project aimed at evaluating the use of geostationary satellites using NASA's Applications Technology Satellites (ATS 1 and 3) for communicating with and locating land vehicles in the United States. The results were very encouraging and indicated a potential use of both geostationary and low-orbiting satellites in assisting DEA in accomplishing its objectives.

The RAMS capability on the Nimbus 6 satellite was suitable for the vehicle location experiment. Thus DEA developed an experiment aimed at evaluating the use of low-orbit satellites to locate and receive data from low-power transmitters on moving targets including automobiles, boats, trains, and trucks, moving at speeds greater than those experienced with buoys.

DEA used three AEL RAMS beacons designed to transmit identification data only. During the last quarter of 1976, successful tracking of transmitters mounted inside wooden and fiberflass boats was demonstrated. The accuracy of RAMS for fixed transmissions was approximately 1 km. Position location accuracy for moving vehicles varied depending upon the velocity vector.

On December 3, 1976, a vehicle carrying two RAMS beacons was driven over Route I–95 from near Baltimore, Md., to south of Fredericksburg, Va., to evaluate the ability of RAMS to track a moving automobile. During

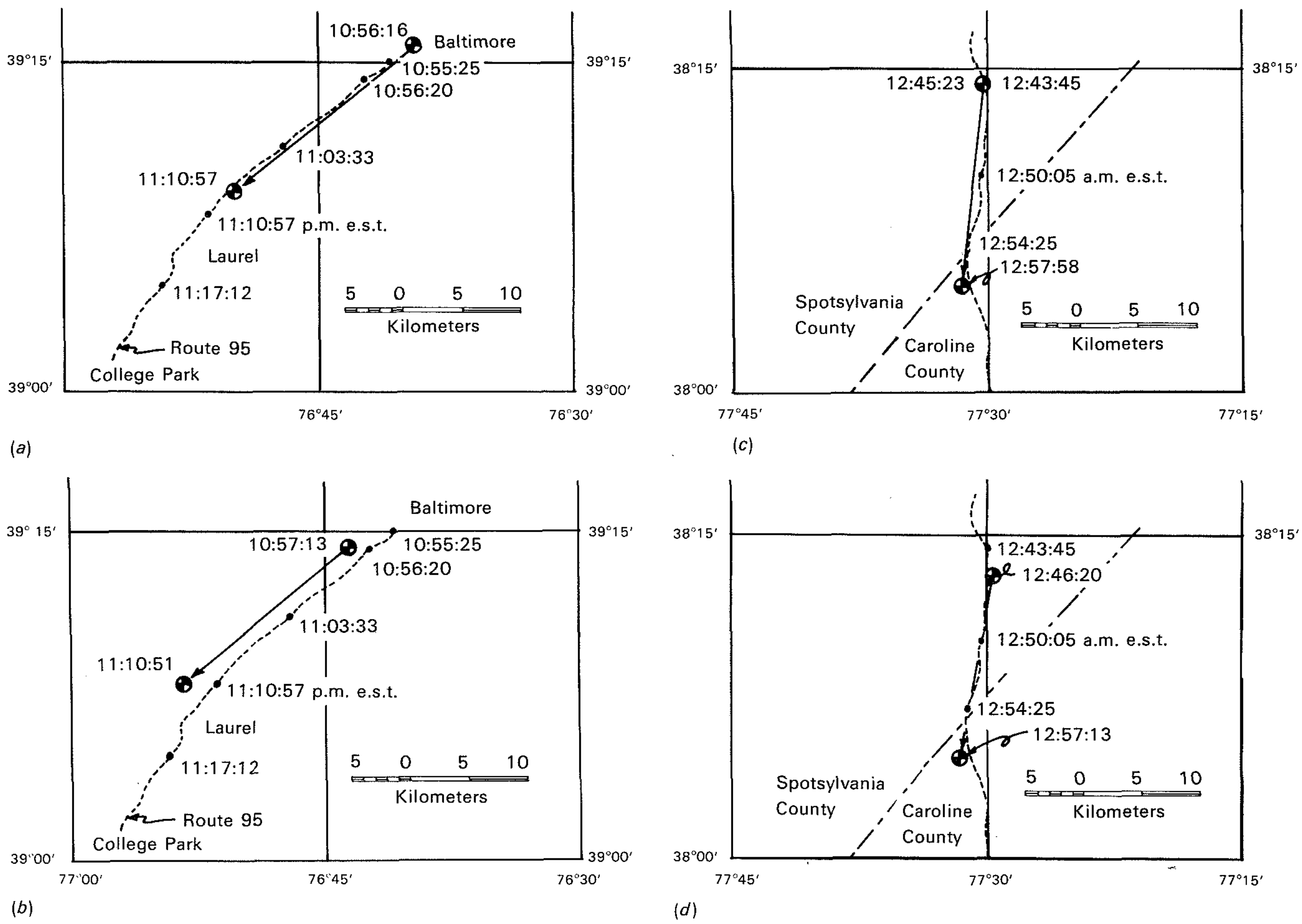


Figure 61.—Vehicle tracking. Solid lines represent vehicle location from Nimbus 6; dashed lines represent vehicle location from voice-recorded speed and corrected heading. (*a*) Platform ID 338, orbit 7232, December 3, 1976. (*b*) Platform ID 222, orbit 7232, December 3, 1976. (*c*) Platform ID 338, orbit 7233, December 4, 1976. (*d*) Platform ID 222, orbit 7233, December 4, 1976.

the trip, there were two successive overpasses of Nimbus 6. Usable transmissions from platform ID 338 totaled 11 for the first overpass and 10 for the second. During these same orbits platform ID 222 provided 13 and 12 transmissions, respectively, for the first and second overpasses. The approximate time of beacon transmission, vehicle speed, and magnetic compass heading were recorded periodically on a voice tape in the automobile.

Figures 61 (*a*) to (*d*) show the computed versus the actual tracks (after correcting a 40° discrepancy in the magnetic compass heading data). The location precision was within 3 km, and there would be little question in this case as to what route the vehicle was traveling during the satellite overpass.

It was concluded that location precision on the order of several kilometers can be accomplished during a single satellite overpass if data describing the vehicle speed and heading were provided. For RAMS, the digital data sent with each transmission could include such information. Real-time readout of data stored in Nimbus 6 would enable location of the vehicle with only several minutes delay.

Egyptian Desert Expedition Tracking

Dr. Ted A. Maxwell, *Smithsonian Institution, Experiment/User No. 25*

Research by NASA and other Government agencies has been underway to develop a search and rescue system that would remain dormant until an emergency occurred and then would react by transmitting a radio signal that would allow rescuers to locate the party involved.

The Nimbus 6 RAMS involved the use of satellite tracking technology and was used in position location and search and rescue experiments that could fulfill the search and rescue warning system need. One of the recent search and rescue experiments involved a Smithsonian Institution sponsored expedition into the Egyptian desert. (See fig. 62.)

The expedition was comprised of 16 U.S. and Egyptian scientists who made two geological field trips into the western Egyptian desert in hopes of unveiling some of its secrets.

During both treks into the desert, a Nimbus 6 RAMS beacon linked the caravan to monitoring facilities at GSFC. The beacon chosen to accompany the desert expedition was a low-powered, economical, compact unit. The 10-lb beacon had only three parts: a fully charged 12-V battery pack, a transmitter with the capability of sending data from four sensors during transmission, and an antenna capable of hemispheric coverage when mounted at the highest point available. During the expedition, both the battery and transmitter operated perfectly; however, there were some problems with the antenna.

Use of the beacon by the expedition aided its members in determining the capabilities of RAMS as a search and rescue system and its ability to be used in the absence of other means of communication. The beacon continuously signaled the location of the expedition. It also was equipped with a special signal switch for emergency use.

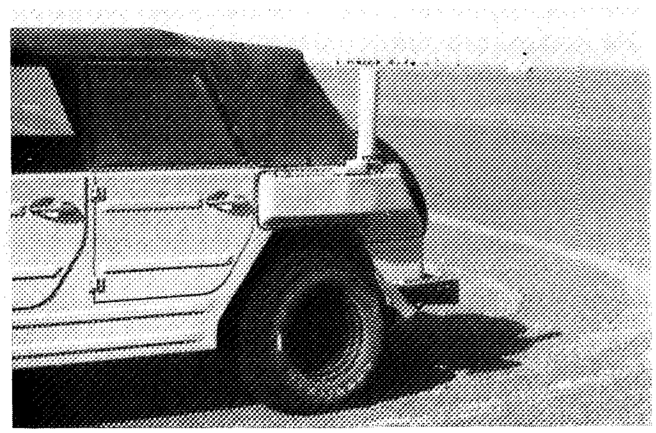


Figure 62.—Desert vehicle carrying Nimbus 6 RAMS beacon. The antenna is mounted on the rear of the vehicle.

In addition to the tracking data collected by Nimbus 6 RAMS, the scientists acquired other potentially useful information. During their first 2-week trek from the Khargo Oasis to Gebel Uweinat, the scientists discovered major iron ore deposits; prehistoric cave paintings of African features; treasures and artifacts of the people who lived in the area approximately 3000 to 4000 years ago when the land was arable; and new information on how deserts are formed.

Trans-Pacific Row in 35-ft Open Boat

Kenneth Crutchlow, *British Marketing Enterprises, Experiment/User No. 37–2*

The goal of this project is to be the first person to row a small boat, solo, across the Pacific Ocean from California to the eastern coast of Australia.

A British mariner named Peter Bird made a first attempt at crossing the Pacific Ocean on October 1, 1980, when he left San Francisco, Calif. Bird used a 35-ft (11-m) rowboat, called *Britannia II* (see fig. 63), that was designed by Uffa Fox for British Royal Navy rescue missions. Bird expected to reach Australia in 9 or 10 months.

The *Britannia II* carried a Nimbus beacon transmitter for operating with the Nimbus 6 RAMS to determine geographical location. The beacon is the same type used on various data collection platforms deployed on lakes or drifting buoys to measure water level or to track ocean currents.

Britannia's Nimbus transmitter sent data bursts each minute that identified the platform transmitter on the boat during about six orbits of the Nimbus satellite each 24-hr day. Bird's data were relayed from the Nimbus 6 satellite to the Fairbanks, Alaska, ground station, and then to GSFC where the data were computer processed and mailed to Bird's San Francisco, Calif., shore station. During times of emergency, this station could contact GSFC directly for the geographical location of Bird's boat.

However, within a week after leaving shore, Bird experienced a series of severe storms, resulting in badly leaking deck hatches and the loss of a single sideband radio antenna, cutting radio communication with shore. A strong westerly wind carried Bird back to Camalu in Baja California, Mexico, on October 23, 1980.

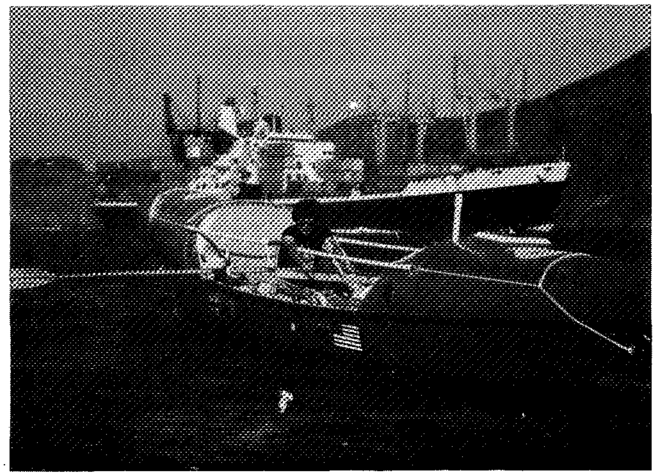


Figure 63.—Peter Bird and his rowboat.

After refitting the hatches and installing a new radio antenna, Bird left Baja California on November 11, 1980.

Bird made good progress southwest for the first 500 miles, then trade winds from the southeast carried Bird's boat off-course in the direction of the Hawaiian Islands. Near the Kaluhui Harbor, Bird's boat ran aground and was destroyed on rocks from high waves, in late February 1981, ending his voyage. Bird escaped to shore.

Undaunted by the failure of his first attempt, Bird plans to depart on his second voyage in mid-May 1982 from San Francisco, Calif., in a new rowboat named *HELE-ON-BRITANNIA.*

Data Buoy Development Experiments

The capabilities of the Nimbus 6 RAMS to detect 1-s transmissions from numerous remote platforms used in oceanographic and meteorological studies throughout the world brought about a new concern for designing and developing smaller, low-cost drifting buoys for operation with satellites.

Two major data buoy development projects were undertaken to develop, deploy, and experimentally test the design configuration, reliability, performance, and other factors associated with a new generation of buoys.

The French Marisonde program developed and deployed a new buoy, designated Marisonde B, which could be used with the Nimbus 6 RAMS in the Atlantic and Mediterranean.

The NOAA Data Buoy Office, through a continuing series of modifications, developed several units that were subjected to extensive analysis and testing during the course of the project.

It is these technology development and design improvement efforts that will lead to operational use of satellite systems for data collection from remote platforms throughout the world.

Project Marisonde

M. Marcel Pétit, *Centre de recherches atmospheriques, Experiment/User No. 46*

In 1974, the Establissement d'etudes et de recherches meteorologiques in France initiated the Marisonde program aimed at designing, developing, building, and deploying a number of meteorological buoys to be used ultimately in the first global GARP experiment. Marisonde A was designed for coastal survey, which relayed data by radio to a nearby coastal station. Marisonde B as seen in figure 64 was a second generation of buoys that were RAMS equipped and were deployed in the Mediterranean Sea and the Atlantic Ocean to validate overall system and equipment performance.

Marisonde B is a very light, easily handled free-floating spar buoy that telemeters barometric pressure and sea water surface temperature via the Nimbus 6 RAMS. It underwent several changes during development. The buoy consists of a cylindrical hull equipped with a biconical float mounted on top with the radio antenna and barometric transducer. The lower end of the tube contains the batteries; the length of tube varies as a function of battery volume; i.e., design life.

Buoys designated B01 and B02 used the SM01 buoy, which measures 4 m long by 26 cm in diameter; the antenna and barometric transducer are unprotected. Buoys B03 through B12 (type BABETH as seen in fig. 65) are housed in a smaller structure, a PVC tube 2 m long by 20 cm in diameter; the antenna and barometric transducer are protected by a conical cap. A collar of elastic material encircling the larger diameter (54 cm) provides a measure of resistance to mechanical shock. A third series, B13 through B60 (type PEMG; PEMG is a French acronym meaning first global GARP experiment), is constructed with a longer 2.5-m tube and carries a small float. Vertical

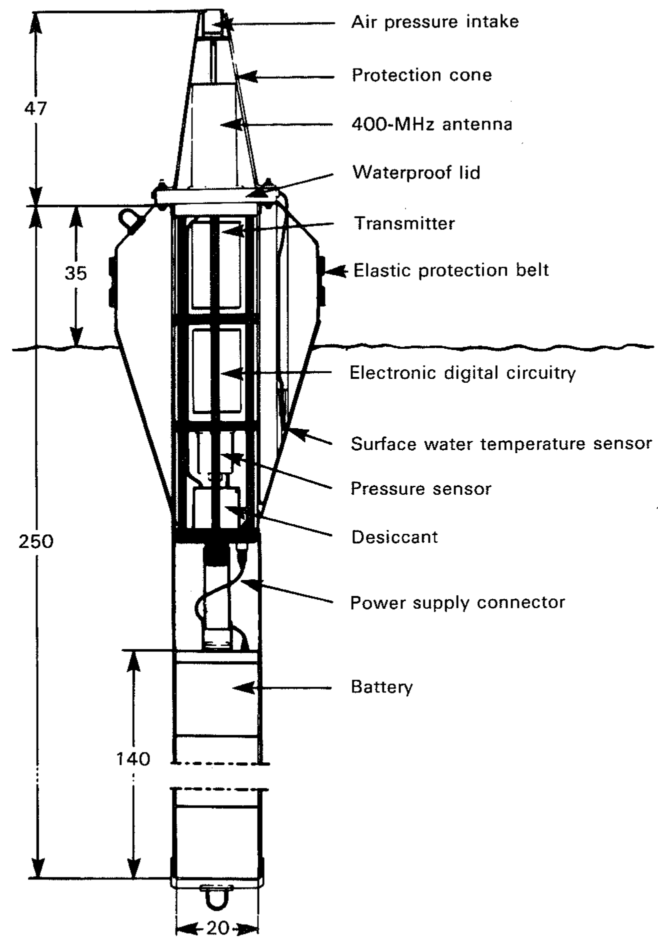


Figure 65.—BABETH components. (Dimensions are in centimeters.)

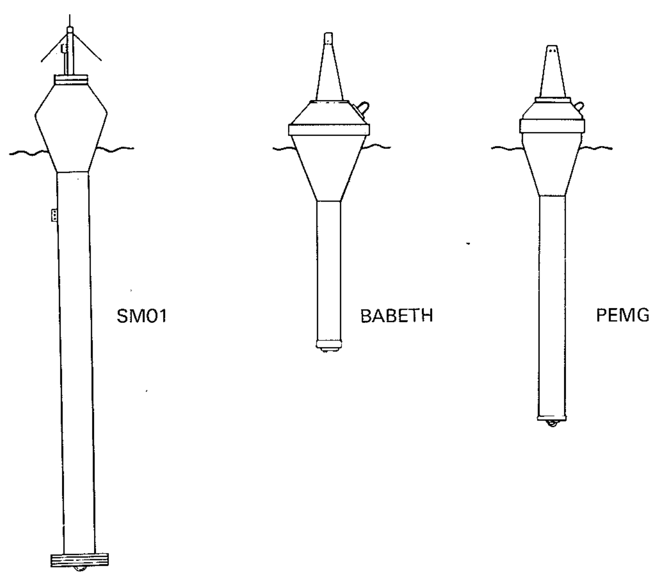
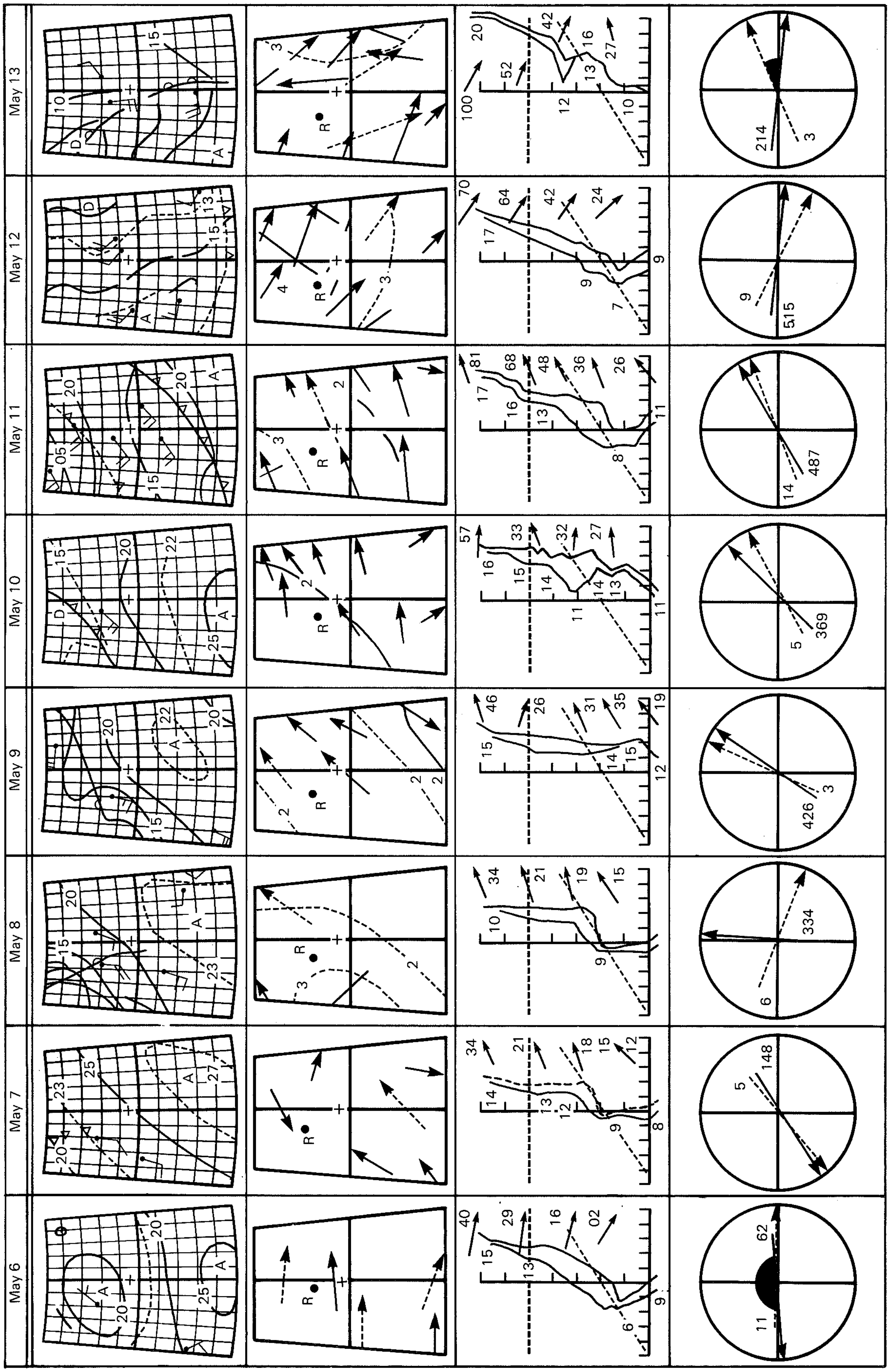


Figure 64.—Marisonde B profiles.

Row 1. These are meteorological charts of the general area of interest showing isobars labeled in thousands of millibars, ship reported wind direction and speed, and fronts. The buoy position is denoted by a cross.
Row 2. The local wind-induced wave direction and height in meters for the same geographic area as in row 1 are shown respectively by solid arrows and wave height isograms (solid lines); the same data for the swells induced by distant disturbances are shown with broken lines. The buoy position is denoted by a cross.
Row 3. These are vertical air mass diagrams at point "Romeo" based on radiosonde data obtained at noon universal time.
Row 4. These diagrams compare the wind vector at "Romeo" (solid arrow) and the buoy course vector (dashed arrow). The velocities (in French nautical miles) are averaged over the 24-hr period centered at noon universal time. The numeral at the extremity of the wind velocity (solid) arrow is the vector sum of 24 hourly observations, while the buoy velocity vector (dashed arrow) is the average over the 24-hr period.

Figure 66.—Meteorological conditions observed daily from May 6 through May 13.


May 13
May 12
May 11
May 10
May 9
May 8
May 7
May 6

stability is improved by either using a 15-m chain weighing about 20 kg attached to the lower ring or by a drogue tethered to the same ring with a 50- to 100-m-long 8-mm-diameter nylon line.

Figure 65 shows the encapsulated components for type BABETH. The barometer measures atmospheric pressure over the 920- and 1050-mb range. The sea water surface temperature monitor is a thermistor with a precision on the order 0.1° C over the −5° to 40° C range, but the output is digitized to only 0.2° C.

Buoy B02 was deployed by the meteorological ship *France 1* on April 20, 1977, near the point "ROMEO" (47° N, 17° W). It transmitted temperature and pressure through June 29. The transmission data ceased on July 7, at which time the buoy was located 190 n. mi. from "ROMEO" on a bearing of 182°. The trajectory derived from RAMS position data plotted on a Mercator projection is given in figure 66. (See p. 87; caption and explanation on facing page.) The daily positions at approximately noon, universal time, are shown as points joined by loxodromes to form the trajectory.

Marisondes B03 and B05 were deployed in the Mediterranean on July 15 and December 22, 1977, respectively. The first of these experiments was performed (July 15 to August 3) with participation of the U.S. Navy and led to interesting particulars about the anticyclonic vortex (see

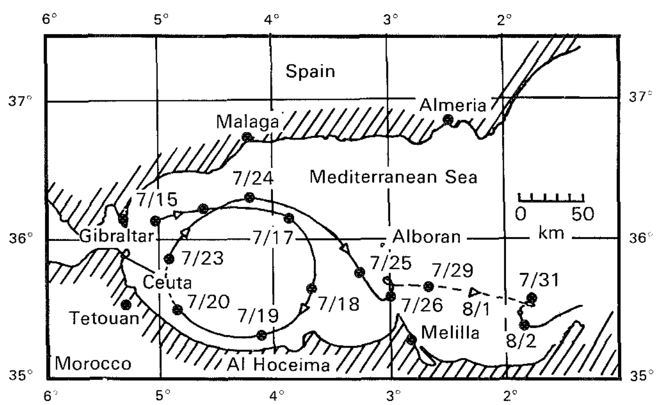
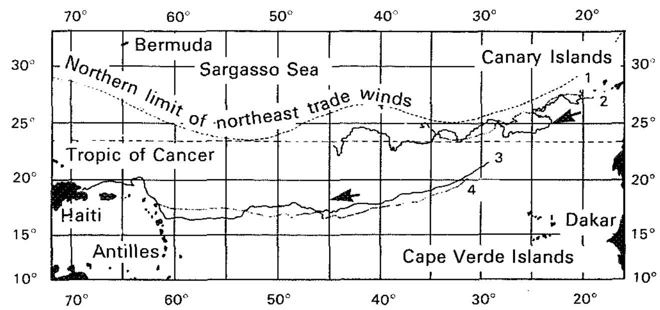


Figure 67.—Marisonde B03 trajectory in the Mediterranean Sea in 1977.



1 Marisonde B04, Nov. 3, 1977, to Nov. 20, 1978
2 Marisonde B06, Mar. 3 to Sept 11, 1978
3 Marisonde B09, May 30, 1978, to Feb. 12, 1979
4 Navisonde N01 (B07), Aug. 18 to Nov. 12, 1978

Figure 68.—Marisonde buoy trajectories in the tropical Atlantic Ocean.

fig. 67) due to the cold ocean currents in the Atlantic that travel from the mouth of the Straits of Gibraltar to the Island of Alboran. Buoy B05 was deployed at 42° N, 6° W, and transmitted until February 2, 1978, when it went aground on the Sardinian coast. It showed a great sensibility to the wind when the wind was above 15 knots, but when it was below that level, the trajectory was very confused.

Marisonde B04 was launched off the Canary Islands on November 3, 1977 and was the first experiment conducted in the tropical Atlantic. Its trajectory ended in the Sargasso Sea after 13 months. Marisondes B06 and B09 were launched on March 3 and May 30, 1978, respectively. B06 ended in the Sargasso Sea on September 11, 1978, and B09 reached San Domingo Island's Bay on February 12, 1979. Their trajectories along with those of B04 and B07 are shown in figure 68. Another buoy, Marisonde B10, was launched in the Gulf of Guinea on July 26, 1978, and it went aground on the island of Marcias Nguema about January 17, 1979.

All of the experiments were achieved through using Nimbus 6 RAMS. Starting with Marisonde B11, the equipment will be designed to comply with the ARGOS system. The data processing is to be performed by the CNES Center in Toulouse, France.

Drifting Buoy Equipment Development

Dr. Michael Hall and E. G. Kerut, *National Oceanic and Atmospheric Administration, Experiment/User No. 47*

The NOAA Data Buoy Office in St. Louis, Mo., is responsible for the development of buoys of many types. This office developed low-cost expendable drifting buoys for use in conjunction with TWERLE RAMS on Nimbus 6. Originally proposed by the NOAA Data Buoy Office in mid-1972, the initial concept was for use with a drogue for measuring ocean currents. However, this concept was later expanded to include measurement of other oceanographic and meteorological parameters including wind speed, barometric pressure, air temperature, sea surface temperature, and water temperature at depths from 5 to 100 m.

The buoy was made up of a low-cost spar hull, a BTT, a UHF antenna, a battery supply, and a minimal sensor site. (See fig. 69.) By the end of 1976, over 200 BTT platforms had been deployed.

The original hulls were made up of PVC plumbing components and a flat-topped conical fiberglass flotation section. The conical shape was selected to provide:

(1) Rapidly increasing buoyancy with increasing vertical displacement

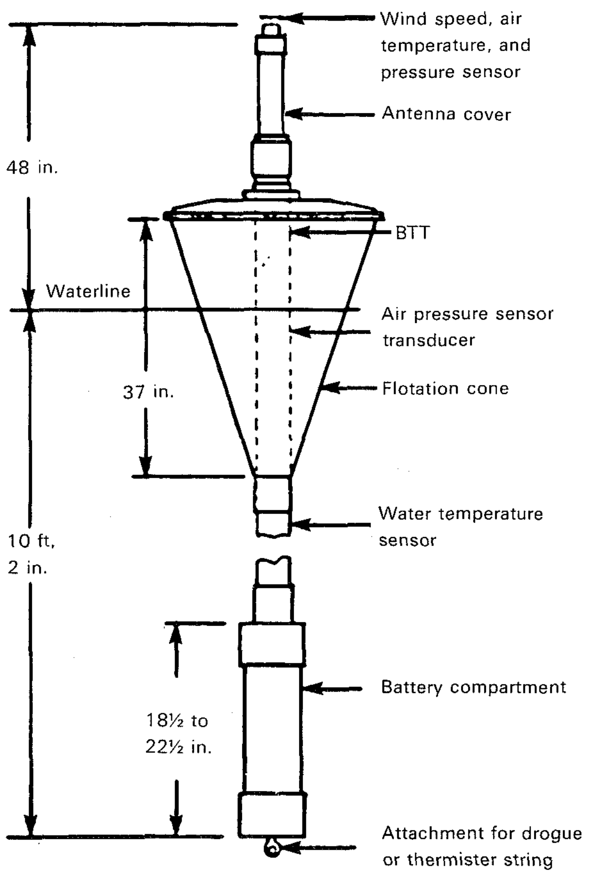


Figure 69.—Moderate environmental drifting buoy.

(2) High natural frequency

(3) Stronge response to waves in order to maintain the antenna above the waves

(4) Low profile to minimize air/wind drag

(5) Minimum hull/surface water drag, to track a water mass at a particular drogue depth with minimum surface current effects

(6) Relatively large outer diameter symmetrical shape for maximum distribution of impact forces while being deployed or should the buoy strike another surface

The flat-top configuration (PCV–0) was intended for operation in moderate seas and was the baseline design. For severe environments, a domed top was added (PVC–1) to elevate the antenna and add more buoyancy. (See figs. 70 and 71.) Subsequent buoys were made of fiberglass or aluminum because of the discovery that PVC becomes extremely brittle when exposed to sunlight. The aluminum-hulled buoy, designated A-COS (fig. 72), was a smaller configuration developed for use in Continental Shelf regions. Both the welded fiberglass and aluminum hulls were shown to be rugged enough to withstand the rigors of transportation across the United States and to other parts of Earth. During 1976, successful shipments were made to Brazil, South Africa, Antarctica, New Zealand, Alaska, Greenland, Norway, France, Japan, Hawaii, and the Drake Passage.

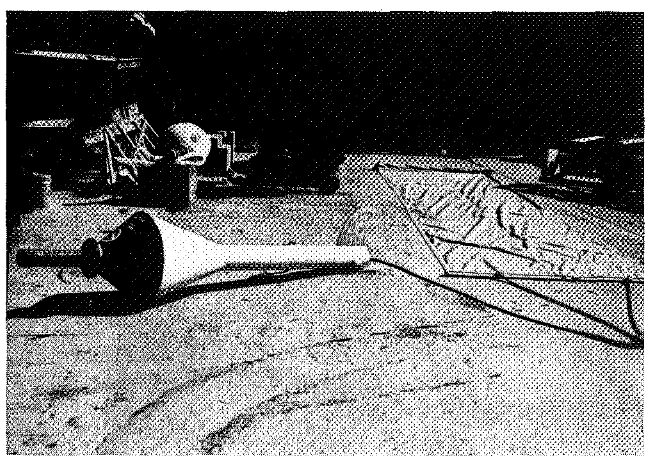


Figure 70.—PVC 1.

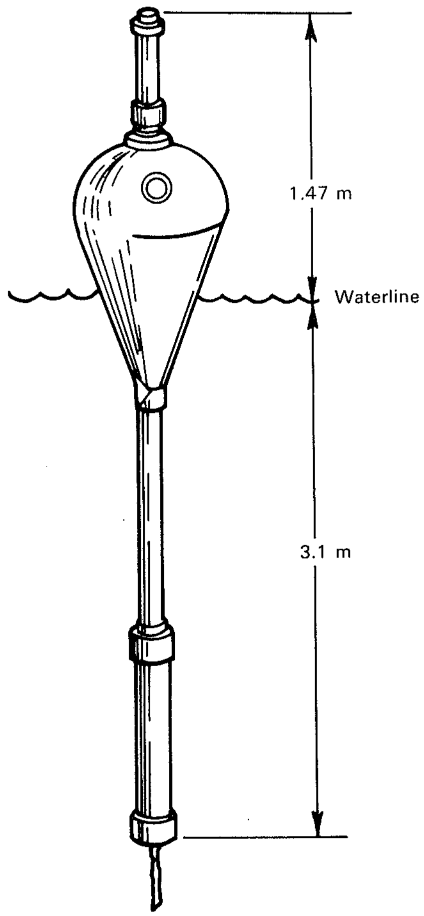


Figure 71.—PVC 1 configuration.

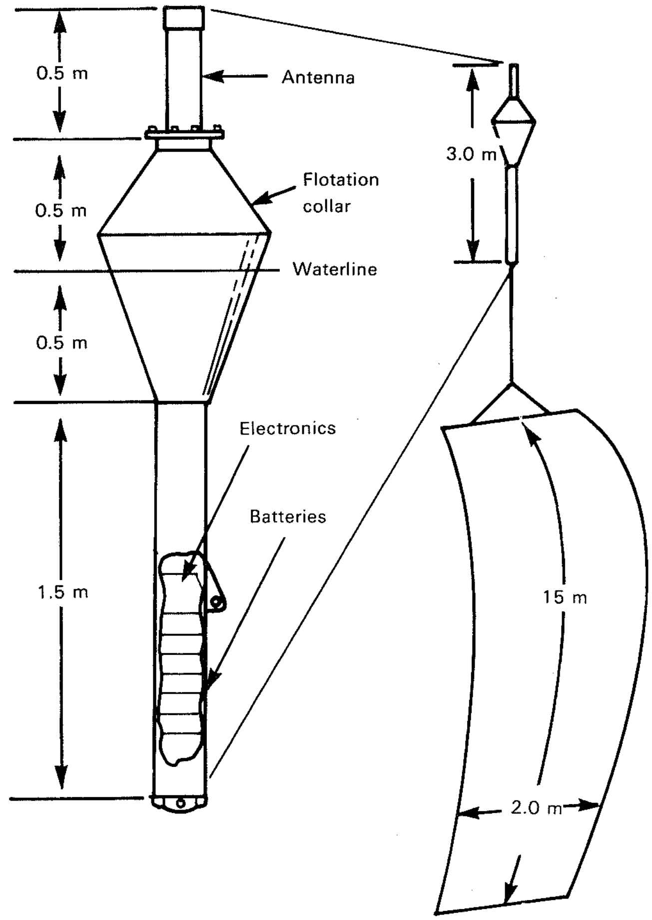


Figure 72.—A-COS configuration.

The BTT unit housed the data and telemetry, which were procured from three different sources designated types A, B, and H. These consisted of digital electronics and a UHF transmitter. Each BTT could accept either analog or digital sensor data, each storing up to eight 8-bit words and transmitting the data to the Nimbus 6 RAMS.

The type A units were the first to be used and underwent a series of modifications. The type A, class 1, units were used in the initial deployments and, because of the tight schedule, were subjected to only limited reliability tests. In addition to an antenna mismatch causing the power amplifier to oscillate, thus rapidly depleting the battery supply, it was found, after 30 of the 70 class 1 units had been deployed, that humidity was adversely affecting the operation and that a number of the transmitter oscillators ceased to function below 10° C. Subsequent modifications to alleviate these and other problems produced class 2 units, which were housed in splashproof metal containers; class 3 units had the preceding feature and incorporated a power amplifier; and, finally, class 4 units consolidated all these features with the inclusion of ceramic instead of plastic complementary metal-oxide semiconductors to further alleviate the humidity problem. By the time type B and type H BTT's were procured, the type A features were incorporated, and ceramic chips were employed.

Minimal sensors were employed and these were limited basically to sea surface temperature, wind speed, and drogue force monitor. The temperature and drogue sensors operated well, but the inexpensive wind speed sensor (a low-priority parameter) was prone to early failure,

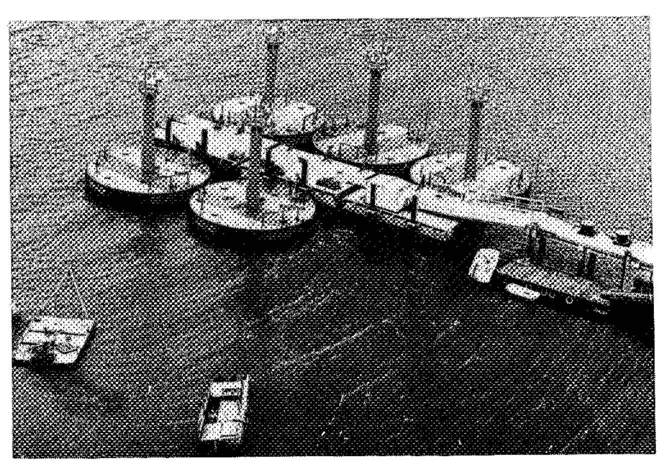


Figure 73.—Large moored environmental buoys.

Table 5.—*BTT Reliability Summary by Type and Class*

Type/class	Days	Units	Failures	Time to failure, days		
				Minimum	Maximum	Mean[a]
A/1	1544	27	16	3	234	83.5
A/2	1670	17	5	29	[b]196	[b]267.2
A/3	4569	42	20	14	[b]305	[b]199.5
A/4	1336	11	7	12	[b]234	[b]156.3
PRL[c]	2148	22	3	54	[b]204	[b]548.0
Handar	6159	50	14	7	[b]215	[b]377.9

A/1 AEL basic unit (plastic chips)
A/2 AEL basic unit with low temperature oscillator, −40° to 45° C
A/3 AEL basic unit with improved power amplifier and −5° to 45° C
A/4 AEL with ceramic chips, heavy duty power amplifier, and −40° to 45° C oscillator

[a]Mean time to failure (MTTF), includes a 75-percent confidence level probability that 75% of randomly selected units will have a MTTF equal to or greater than the value indicated.
[b]Active experiments as of the end of 1976.
[c]Battery life = 180 days.

probably due to the unsealed anemometer shaft bearings binding up from salt spray corrosion.

A number of barometric pressure sensors were deployed with limited success. By the end of 1976, comparison experiments were being conducted aboard a large moored environmental buoy (like the one in fig. 73) on transducers manufactured by various companies.

Three types of power supplies were used. The original PVC buoys employed a zinc-carbon battery pack for operation in tropical areas. These operations were rather successful considering the fact that a number of buoys were stored for several months in uncontrolled climatic conditions, which no doubt reduced their useful life expectancy.

The use of drifting buoys in cold climates led to the employment of alkaline cells because of their low cost and good low-temperature characteristics. Both the zinc-carbon and alkaline batteries exhibited a fairly linear decrease in voltage versus operating time, so that a voltage monitor was used as a reasonable check on system operation (i.e., current drain). To assure adequate power availability for a design lifetime of 6 to 12 months, it was necessary that the initial voltage be about 15 V. The minimum operating voltage of the BTT's was 9.5 V.

The third type of batteries employed were mercury cells successfully used by Scripps Institution of Oceanography in drifting buoys of their own design with very similar electronics. These cells produce nearly constant voltage until depletion.

Antennas employed were two vertical polarization dipole designs, one by Comant Industries, Inc. (C1 130), and the other by PRL, one of the buoy suppliers. The third type, the CA3192, was a right-hand circularly polarized "volute" designed to provide low-angle coverage. It was procured from Chu Associates.

Because the buoy is subject to submergence, the antenna had to be sealed. In the case of the fiberglass buoys, the antenna was completely encapsulated in epoxy. Double shell housing of fiberglass with reinforcing gussets at the antenna base provided a convenient "handle" structurally capable of withstanding the bending moment resulting from the weight of the buoy.

A summary of the reliability analysis of all known buoy deployments from Nimbus 6 launch through December 15, 1976, is given in table 5. The confidence factor represents the probability that 75 percent of randomly selected units will have a value of MTTF equal to or greater than the value indicated.

One use of the lightweight design was the deployment of a Nimbus RAMS tracked buoy off Nantucket Island on December 31, 1976, to help track the *Argo Merchant* 7.6-million-gallon oil spill. This buoy was provided with a flotation collar and was dropped into the ocean by a U.S. Coast Guard helicopter. The request was made by the NOAA/U.S. Coast Guard Spilled Oil Research Team. The buoy was successfully tracked past the end of January 1977.

Sea Ice Buoy Program

Dr. John J. Kelly, *Naval Arctic Research Laboratory, Experiment/User No. 49*

This experiment was conducted with the aid of the Nimbus 6 RAMS satellite and an ADRAMS navigation buoy at the Institute of Marine Science, University of Alaska, Fairbanks, Alaska.

The experiment objective was to follow the course of an unmanned ice island (Fletcher's Ice Island T–3) during its drift in the western Arctic Ocean.

T–3 was observed to be moving southward through the Beaufort Sea during June 1976. Observations from occasional satellite photographs charted its course as it slowly drifted along its traditional pathway in the Beaufort gyre. When it came within the range of Naval Arctic Research Laboratory's aircraft, it was visited several times to ascertain the condition of the camp and equipment. It was found that the size of the island had not appreciably decreased (approximately 6.5 by 14.5 km) and that it could be reactivated quickly.

By October 1, 1979, T–3 began to drift rapidly toward the west. It appeared that the ice island might depart the region of the Beaufort gyre. Its trajectory suggested that it might be on a new course toward the East Siberian Sea and the eastern Arctic Ocean. If it continued on this course, it might exit the Arctic Ocean and end its long history by breaking up in the Greenland Sea.

An ADRAMS buoy was installed on T–3 on February 19, 1980. Reports from NASA on the position of T–3 commenced on March 1, 1980 (table 6). After February 19, 1980, no further visitations were made to the ice island. It continued along its westerly drift until the ADRAMS lost power and ceased to transmit signals to the Nimbus 6 satellite. The last position of T–3 was received on July 3, 1980.

Table 6.—*Positions of Ice Island T-3 Derived From Nimbus 6 ADRAMS Data in 1980*[a]

Date	Latitude (N)	Longitude (E)
Mar. 1	73°52′	174°47′
Mar. 2	73°47′	174°52′
Mar. 9	73°45′	174°45′
Mar. 13	73°46′	175°2′
Mar. 17	73°40′	175°18′
Mar. 18	73°42′	175°23′
Mar. 24	73°43′	175°
Apr. 3	73°43′	174°11′
Apr. 23	73°51′	174°26′
Apr. 26	73°39′	174°20′
Apr. 27	73°34′	174°34′
May 8	73°36′	173°43.5′
May 9	73°30′	175°51′
May 16	73°43′	173°59′
May 20	73°57′	172°23′
May 22	74°07′	171°38′
May 26	74°32′	170°08′
June 1	74°38′	168°30′
June 2	74°39′	168°25′
June 3	74°41′	168°21′
June 6	74°45′	168°8′
June 7	74°44′	168°9′
June 11	74°36′	169°3′
July 3	74°36′	169°3′

[a]Aug. 25: ADRAMS buoy no longer operational.

New Technology for Future Applications

The Nimbus 6 RAMS technology and applications experiments have contributed significantly to a continuing improvement in the capabilities of polar-orbiting satellites to locate and retrieve data from moving platforms. However, present systems, such as RAMS, that use doppler processing techniques have the following inherent limitations:

(1) The ground transmitters require highly stable oscillators to achieve the required location estimation accuracy. This requirement contributes substantially to their cost.

(2) The average velocity of a moving transmitter, such as one on board a balloon, can only be estimated from frequency measurements acquired from two consecutive overpasses of a satellite. This is too coarse an estimate for many applications. Velocity errors on the order of meters per second, independent of satellite overpass geometry, based upon a single satellite overpass, are highly desirable.

(3) The accuracy of the position estimate is dependent on location with respect to the satellite path. In particular, the error in the direction perpendicular to the ground track is very large for platforms located near the ground track. Location errors on the order of 1 km, relatively independent of overpass geometry, are highly desirable.

A new satellite-based location technique being studied by NASA GSFC, uses multiple antennas to determine the direction of arrival of the signal of a ground platform. This method, known as radiofrequency interferometry, does not suffer from the drawbacks of the doppler technique. It has the capability of estimating location on the basis of a single received pulse, while doppler systems require several.

These radiofrequency interferometer locations systems, when combined with data collection capabilities, have several possible application areas. In environmental monitoring and scientific data collection, the advantage of low platform transmitter cost would allow mass deployments to study widely distributed phenomena such as ocean or air currents. The capability to estimate velocity in one overpass lends itself to meteorological balloon tracking, as well as to various vehicle-tracking applications. Furthermore, a radiofrequency interferometer system, because of its ability to arrive at a position estimate upon receiving a single platform transmission, is also particularly well suited to a search and rescue application in which the number of transmissions received from an emergency locator transmitter may be limited by line-of-sight blockage by terrain and other obstructions.

Simpler and less expensive platforms with on-board microprocessors for data handling will allow many disciplines to expand and improve their investigations and operations. Oceanography, search and rescue, navigation, commercial fishing, hydrology, and fish and wildlife behavior and movement will be among those disciplines employing satellite communication and navigation to a greater extent.

Thus, with the rapid increase in and demand for information from data collection platforms of this type, systems dedicated to location and retrieval of data from mobile platforms in the atmosphere, the ocean, and lithosphere should play an important role in our future.

Appendix—List of Nimbus 6 RAMS Applications Experiments

The response from scientists and investigators who used the capabilities of the Nimbus 6 RAMS for obtaining data in a number of discipline-oriented research investigations exemplifies the potential of this satellite system concept.

The experiments described in the preceding pages of this book are representative of the wide variety of investigations performed during the 1975–79 time period. Many of the experiments were highly successful; others experienced difficulties from the outset and could not be completed. This appendix lists each of the experimenters involved in the Nimbus 6 RAMS project.

Experiment/ user number	*Experiment*	*Principal investigator*	*Address*
2	Tropical wind, energy conversion, and reference level experiment (TWERLE)	Dr. Paul Julian (1975–76)	National Center for Atmospheric Research Boulder, CO 80303
3	Sea turtle (*Caretta caretta*) migration and movement in the South Atlantic Ocean	Dr. D. L. Stoneburner (1978–80)	National Park Service 1895 Phoenix Blvd. Atlanta, GA 30349
5	Distress communication and location system for small craft	James L. Baker (1976–80)	Baker Development Corp. 4 Beach Rd. Sherwood Forest, MD 21405
6–1	Arctic ice dynamics joint experiment	Dr. Norbert Untersteiner (1975–76)	University of Washington 4059 Roosevelt Way, NE. Seattle, WA 98105
6–2	Satellite radio tracking of polar bears	Dr. Douglas De Master (1979–80)	108 Zoology 318 Church Street, SE. Minneapolis, MN 55455
7	Lagrangian surface current	Dr. Donald V. Hansen (1975–78)	Atlantic Oceanographic and Meteorological Laboratories National Oceanic and Atmospheric Administration 15 Rickenbacker Causeway Miami, FL 33149
8–1	Carrier balloon	Vincent E. Lally (1975–76)	National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80303
8–2	Northern Bering Sea ice	Douglas C. Echert (1978–79)	Oceanographic Services, Inc. 25 Castilian Dr. Goleta, CA 93017
9	RAMS collection of meteorological and position data in the Norwegian Sea	Jack Nordo (1975–79) Dr. Carl Kolderup Jensen (1975–79)	Det Norske Meteorologiske Institutt Neils Henrik Abels vei 40 Blindern, Oslo 3 Norway
10	A study of the Gulf Stream using satellite-tracked drogued surface buoys	Dr. Phillip L. Richardson (1975–80)	Woods Hole Oceanographic Institution Woods Hole, MA 02543
11	Bay of Biscay drifting buoy	R. Kalinowski (1976–78)	Centre national pour l'exploitation des oceans COB 29 N-Plouzane, BP 337 29273 Brest Cedex France
12	Gulf Stream ring tracking using COSRAMS air deployable buoys	Robert E. Cheney (1978–80)	Code 921 NASA Goddard Space Flight Center Greenbelt, MD 20771

Experiment/ user number	*Experiment*	*Principal investigator*	*Address*
13	Tracking of icebergs in the Arctic and western Atlantic oceans	Wayne Crocker (1977–79) Dr. W. E. Russell (1979–80)	Newfoundland Oceans Research and Development Corp., Ltd. P.O. Box 8833 St. Johns, Newfoundland A1B 3T2 Canada
14	Surface drifter buoys in the Davis Strait	Michel Metge (1977–78) Kelvin N. Wood (1978–80) L. G. Spedding (1980–81)	Esso Resources Canada, Ltd. 339 50th Ave., SE. Calgary, Alberta T2G 2B3 Canada
15–1	Satellite radio tracking of polar bears	Jack W. Lentfer (1975–79)	Alaska Department of Fish and Game 210 Ferry Way Juneau, AK 99801
15–2	Antarctic automated weather stations	Dr. Allen M. Peterson (1978–80)	Electrical Engineering Department Stanford University Stanford, CA 94305
16	Arctic research in environmental acoustics	Beaumont M. Buck (1975–80)	Polar Research Laboratory 123 S. Barbara St. Santa Barbara, CA 93101
17–1	Albacore oceanography drifter study	Ronald J. Lynn (1977–78)	Southwest Fisheries Center National Marine Fisheries Service National Oceanic and Atmospheric Administration P.O. Box 271 La Jolla, CA 92038
17–2	Use of RAMS in following trans-Atlantic balloon attempts	Nicholas Craddock (1977–78)	Federal Aviation Administration AAT 310 Washington, DC 20591
17–3	Satellite tracking of the *Pride of Baltimore*	Thomas Norton (1979–80) Gail Shawe (1980–81)	Baltimore Office of Promotion and Tourism 110 West Baltimore St. Baltimore, MD 21202
18	Currents in the eastern Indian Ocean and Tasman Sea	Dr. George Cresswell (1975–81)	Commonwealth Scientific and Industrial Research Organization P.O. Box 21 Cronulla New South Wales 2230 Australia
19–1	Drifting buoy	Dr. A. J. Dyer (1976–78)	Commonwealth Scientific and Industrial Research Organization Station St. Aspendale, Victoria 3195 Australia
19–2	Tracking of basking sharks	Dr. I. G. Priede (1978–79)	Zoology Department University of Aberdeen Tillydrone Ave. Aberdeen AB9 2TN United Kingdom
20–1	GARP Atlantic tropical experiment	Prof. Henri Lacombe (1975–76)	Laboratoire d'oceanographie physique Museum national d'histoire naturelle 43–45 Rue Cuvier 75005 Paris France
20–2	Antarctic sea ice data buoys	Stephen F. Ackley (1978–80)	Snow and Ice Branch U.S. Army Cold Regions Research and Engineering Laboratory Hanover, NH 03755
21	Ice drift experiment in the Svalbard-Greenland area	Torgny Vinje (1975–80)	Norsk Polarinstitutt Rolfstangveien 12 Postboks 158 1330 Oslo Lufthavn Norway
		Thor Haegh (1975–80)	Royal Norwegian Council for Scientific and Industrial Research Wdm. Thranes gt. 98 Oslo 1 Norway

Experiment/ user number	*Experiment*	*Principal investigator*	*Address*
22–1	Outer Continental Shelf environmental assessment project (OCSEAP)	Dr. Thomas L. Kozo (1979)	Polar Science Center University of Washington 4057 Roosevelt Way, NE. Seattle, WA 98105
22–2	Marine sea turtle tracking	Scott Searcy (1980–81)	P.O. Box 1207 Pascagoula, MS 39567
23–1	Free drifting buoys in the Indian Ocean (INDEX)	Dr. Henry Stommel (1975–78)	Woods Hole Oceanographic Institution Woods Hole, MA 02543
23–2	Ice floe tracking in the Arctic	William S. Dehn (1978–80)	Sea Ice Consultants 4710 Auth Pl., Suite 175 Camp Springs, MD 20023
24–1	Mountain wind project	Patrick J. Kennedy (1977–78) Dr. Julian Pike (1978–79)	National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80307
24–2	Marine sea turtle tracking	Robert Timko (1979–81)	National Marine Fisheries Service National Oceanic and Atmospheric Administration Building 1100 NSTL Station, MS 39529
25	Egyptian desert expedition tracking	Dr. Ted A. Maxwell (1978)	National Air & Space Museum Smithsonian Institution Washington, DC 20560
26	Northeast Greenland weather data	Jorgen Taagholt (1977–78)	Ionosphere Laboratory Technical University of Denmark Building 349, DK-2800 Lyngby Denmark
27–1	Drift buoy component, NORPAX anomaly dynamics study (ADS)	Dr. A. D. Kirwan, Jr. (1975–80)	Department of Oceanography College of Geosciences Texas A&M University College Station, TX 77843
27–2	Tracking of the Kuroshio	Dr. A. D. Kirwan, Jr. (1977)	Department of Oceanography College of Geosciences Texas A&M University College Station, TX 77843
28	Free floating buoys to support atmospheric modeling over the South Indian and Southern Pacific Oceans	H. N. Brann (1975–76) Dr. D. E. Handcock (1976–79)	Department of Science Melbourne, Victoria 3001 Australia
29	Environmental studies off shore Greenland: ice tracking 1977 and 1978	Jan Dietrich (1977–79) Dr. R. Zorn (1979–81)	Danish Hydraulic Institute Agern Alle DK-2970 Horsholm Denmark
30	Mesoscale ocean variability	Dr. John Garrett (1975–81)	Environment Canada 1230 Government St. Victoria, British Columbia Canada
31	A study of the Antarctic circumpolar current	Prof. P. Tchernia (1975–79)	Museum d'histoire naturelle de Paris 43 Rue Cuvier Paris France
32	United Kingdom drifting buoy project	Robert R. Dickson (1975–79) H. W. Hill (1975–79)	Ministry of Agriculture Fisheries and Food Lowestoft, Suffolk, England United Kingdom
33–1	Dog sled tracking	Dr. Lee Houchins (1978)	5049 Garfield St., NW. Washington, DC 20016
33–2	New England Outer Continental Shelf physical oceanography program (NEOCSPO)	Ronald A. Franklin (1978–80)	Raytheon Co. Box 360 Portsmouth, RI 02871
34	Satellite-linked porpoise tracking system (engineering development)	E. G. Woods (1977–79) Dr. A. Kemmerer (1979–81)	National Space Technology Laboratory National Oceanic and Atmospheric Administration Bay Saint Louis, MS 39529
35	Stratospheric monitoring with long-term balloon flights	Dr. P. Roger Williamson (1976–78)	Center for Research in Aeronomy UMC-41 Utah State University Logan, UT 84322

Experiment/ user number	*Experiment*	*Principal investigator*	*Address*
36	Polar pack ice tracking in the Beaufort Sea	J. C. O'Rourke (1976–80)	Canadian Marine Drilling, Ltd. P.O. Box 200 Calgary T2P 2H8 Canada
37–1	Polar automatic meteorological station	Dr. Michael J. Sites (1975–76)	Stanford Electronics Laboratories 225 Durand Bldg. Stanford, CA 94305
		Prof. Robert J. Renard (1977–81)	Department of Meteorology Naval Postgraduate School Monterey, CA 93940
37–2	Trans-Pacific solo row	Kenneth Crutchlow (1978–80)	British Marketing Enterprises 17421 Keaton Ave. Sonoma, CA 95476
38–1	Gravity wave	Dr. Verner E. Suomi (1975)	Space Science and Engineering Center University of Wisconsin 1225 West Dayton St. Madison, WI 53706
38–2	Surface current and ice movement studies near the eastern entrance of Parry Channel	Dr. J. R. Marko (1978–80)	Arctic Science Ltd. 9860 West Saanich Rd. RR2 Sidney V8L 351 Canada
39	Lagrangian drift measurements of sea surface currents and iceberg tracking	Capt. E. A. Delaney (1975–77) Capt. K. M. Palfrey (1977–80)	Oceanographic Unit U.S. Coast Guard Building 159E Navy Yard Annex Washington, DC 20590
40	Ice motion measurement in the Canadian Arctic and offshore Labrador	Dr. R. H. Goodman (1976–78) Robert C. Atkins (1978–79)	Innovative Ventures, Ltd. 4632 11th St., NE. Calgary, Alberta T2E 2W7 Canada
41–1	West Greenland iceberg drift and ocean current investigations	Larry Brooks (1976)	Chevron Oil Field Research Co. P.O. Box 446 La Habra, CA 90631
41–2	Georges Bank larval herring patch study and drift pattern measurements off southwestern Nova Scotia	Dr. Ronald W. Trites (1979)	Bedford Institute of Oceanography Dartmouth, Nova Scotia B2Y 4A2 Canada
41–3	Satellite linked tracking (marine biology)	Jacqueline Jennings (1977–81)	Southwest Fisheries Center National Marine Fisheries Service National Oceanic and Atmospheric Administration P.O. Box 271 La Jolla, CA 92038
42–1	Atlantic north equatorial countercurrent drifting buoy monitoring	Dr. John D. Cochrane (1976–78)	Department of Oceanography College of Geosciences Texas A&M University College Station, TX 77843
42–2	Ocean circulation as seen by satellite tracked drifting buoys	Gerard J. McNally (1978–80)	Scripps Institution of Oceanography University of California, San Diego A-030 La Jolla, CA 92093
43	Western boundary eddies of the Gulf Stream	Dr. Fred M. Vukovich (1977)	Research Triangle Institute P.O. Box 12194 Research Triangle Park, NC 27709
44	Vehicle tracking and location	Gerald Carp (1976–77) John Sugrue (1977–81)	Drug Enforcement Administration Research & Development Facility 2801 Merrilee Dr. Fairfax, VA 22031
45	Monitoring of moored surface floats	Dr. David Halpern (1976–79)	NOAA Pacific Marine Environment Laboratory University of Washington WB-10 Seattle, WA 98195
46	Project marisonde	M. Marcel Pétit (1976–79)	Centre de recherches atmospheriques Magny-les-Hameaux France

Experiment/ user number	*Experiment*	*Principal investigator*	*Address*
47	Drifting buoy equipment development	Dr. Michael Hall (1975–76) E. G. Kerut (1976–81)	Data Buoy Office National Space Technology Laboratory National Oceanic and Atmospheric Administration Bay St. Louis, MS 39529
49	Naval Arctic Research Laboratory sea ice buoy program	Dr. John J. Kelly (1977–80)	Naval Arctic Research Laboratory Barrow, AK 98723

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Return